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ENVIRONMENTAL ANALYSIS OF COOPERATIVE RESEARCH CONTRACT FOR THE MARYSVILLE, GEOTHERMAL PROJECT (DEEP RESEARCH WELL PHASE)

BUREAU OF LAND MANAGEMENT
DISTRICT OFFICE
P.O. BOX 4427
MISSOULA, MONTANA 59801

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IN REPLY REFER TO:

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT
District Office
1819 Holborn Street
Missoula, Montana 59801

U.S. Department of the Interior
APR 1974
Bureau of Land Management
Idaho State Office
Boise Idaho

RESOURCES
Date: 4-22
Chief m
Com:
Action:

The attached environmental analysis concerns the deep test well phase of the geothermal research being conducted near Marysville, Montana. Based on this analysis we believe that no environmental impact statement is required.

If you have comments or suggestions on this environmental analysis, I would be pleased to hear from you.

/s/ John F. Fields
District Manager

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ITEM HAS BEEN DIGITIZED

CONTENTS

I. INTRODUCTION 1

II. DESCRIPTION OF PROPOSED ACTION AND ALTERNATIVES 2

- A. Proposed Action 2
  - 1. Site Preparation 7
    - a. Land Clearing 7
    - b. Soil 7
    - c. Earthwork. 7
    - d. Water Source and Storage 10
    - e. Service Road 13
    - f. Drill Pad (Cellar) 13
    - g. Diesel Fuel 14
    - h. Settling Pond 14
    - i. Waste Disposal 15
    - j. Parking Area 15
    - k. Archaeological Values 15a
    - l. Visitor Management and Policing. 15a
    - m. Safety and Fire Protection 16
  - 2. Site Abandonment 17
- B. Alternatives 17

III. DESCRIPTION OF THE EXISTING ENVIRONMENT 18

- A. Non-Living Components. 18
  - 1. Land 18
  - 2. Air 22
  - 3. Water 23
- B. Living Components. 27
  - 1. Plants. 27
    - a. Aquatic. 27
    - b. Terrestrial. 27

ITEM HAS BEEN DIGITIZED

    2. Animals 27
        a. Aquatic 27
        b. Terrestrial 27
  C. Ecological Interrelationships 28
  D. Human Values 29
    1. Landscape Character 29
    2. Socio-cultural Interests 30
IV. ENVIRONMENTAL IMPACTS OF PROPOSED ACTION 31
  A. Anticipated Impacts 31
  B. Possible and Recommended Mitigating or Enhancing Measures 32
  C. Residual Impacts 33
V. RELATIONSHIP BETWEEN SHORT TERM USE AND LONG TERM PRODUCTIVITY . . . 33
VI. IRREVERSIBLE AND IRRETRIEVABLE COMMITMENT OF RESOURCES 34
VII. PERSONS, GROUPS, GOVERNMENT AGENCIES CONTACTED 34
VIII. INTENSITY OF PUBLIC INTEREST 38
IX. PARTICIPATING STAFF 38
X. RECOMMENDATION ON ENVIRONMENTAL STATEMENT 38
XI. SIGNATURES 40

APPENDIX A - Heat Flow in a Blind Geothermal Area near Marysville, Montana A-1

APPENDIX B - Cooperative Research Contract B-1

ILLUSTRATIONS

Figure 1 Planned Geothermal Resource Development 4
Figure 2 Index Map 5
Figure 3 Deep Well Profile 8
Figure 4 Photograph of Typical Drill Rig 9
Figure 5 Maps of Drill Site and Vicinity 11
Figure 6 Photograph of Drill Site Looking East 12
Figure 7 Photograph of Drill Site Looking West 19
Figure 8 Photograph of Empire Creek Drainage 20
Figure 9 Photograph of Concentrator Tailings and Dams. 24
Figure 10 Photograph of Empire Creek Below Site 25

TABLES

Table 1 Average Precipitation at Marysville, Montana 26

I. INTRODUCTION

An environmental analysis (technical report) for this project was prepared by Battelle-Northwest Laboratories (dated February 15, 1974) and submitted to the Bureau of Land Management. Information from this report was utilized along with BLM resource data to develop this Environmental Analysis Report (EAR).

This analysis will be limited to only one phase of the research project -- the drilling and testing of a deep well, as described under Description of the Proposed Action and Alternatives. Continuation of the research project will be dependent upon the results of this phase and therefore is speculative at this time. If proposals for continuation of the research beyond this phase are made, the environmental impact thereof will be further analyzed, and if appropriate, a statement will be issued.

References necessary for a full understanding of this EAR include: A Special Initiative Research Proposal for the Evaluation of a Geothermal Area of Abnormally High Heat Flow at Marysville, Montana, 211B01410, to Research Applied to the Nation's Needs (RANN), National Science Foundation, 1800 G Street, Washington, D.C. 20550, February 2, 1973; and the Marysville, Montana, Geothermal Project Preliminary Report, November 12, 1973.

The principal project researchers are;

Battelle-Northwest, Richland, Washington

Donald H. Stewart, Director, Geothermal Programs

William R. McSpadden, Project Manager

Southern Methodist University, Dallas, Texas

David D. Blackwell, Associate Professor of Geophysics

Rogers Engineering, San Francisco, California

James Kuwada, Vice President, Engineering

Systems Science & Software, LaJolla, California

Russell E. Duff, Manager, Radiation and Fluid Physics Division

The project is sponsored by the RANN Division of the National Science Foundation (NSF). The NSF Program Manager is Ritchie B. Coryell.

II. DESCRIPTION OF PROPOSED ACTION AND ALTERNATIVES

A. Proposed Action

The proposed action is to revise the existing Cooperative Research Contract (see Appendix B) to authorize the deep test well drilling phase of an on-going research project.

The well site is in T. 12 N., R. 6 W., PMM, Sec. 32, in the valley of Empire Creek near Marysville in southwestern Lewis and Clark County, Montana (see Figures 2, 5, and 8). Vehicle access to the drill site is provided by mountainous roads and trails from several directions, but the best access route is on a gravel-surfaced road along Empire, Lost Horse, and Prickly Pear

Creeks to Canyon Creek, thence to Helena via Montana Highway 279 and Interstate 15. The road distance from Helena to the site via this route is about 35 miles.

The objective of this research project is to investigate a geothermal anomaly of high heat flow discovered in 1969 in west-central Montana, and to determine how this natural resource might be developed as a source of useful energy. Under Phase I, the natural resource will be explored, drilled, and modeled at an estimated cost of $2,588,935 over a 3-year period. Phase II, depending upon the nature of the heat source, will be to develop the resource under a cooperative effort of government and private industry. This environmental analysis is intended to cover the drilling and logging operations noted under Phase I, the only work being undertaken at this time. As can be seen from Figure 1, further tests may be run at this site in later phases of the study. But since the nature of these tests are highly dependent on the results of Phase I, it is not considered productive to speculate on their environmental impact. As shown in Figure 1, however, any later experiments would cover a range of underground experiments, some of which consume water and others which would produce water. Before a meaningful analysis of such work can be written, it will be necessary to analyze the results of Phase I findings.

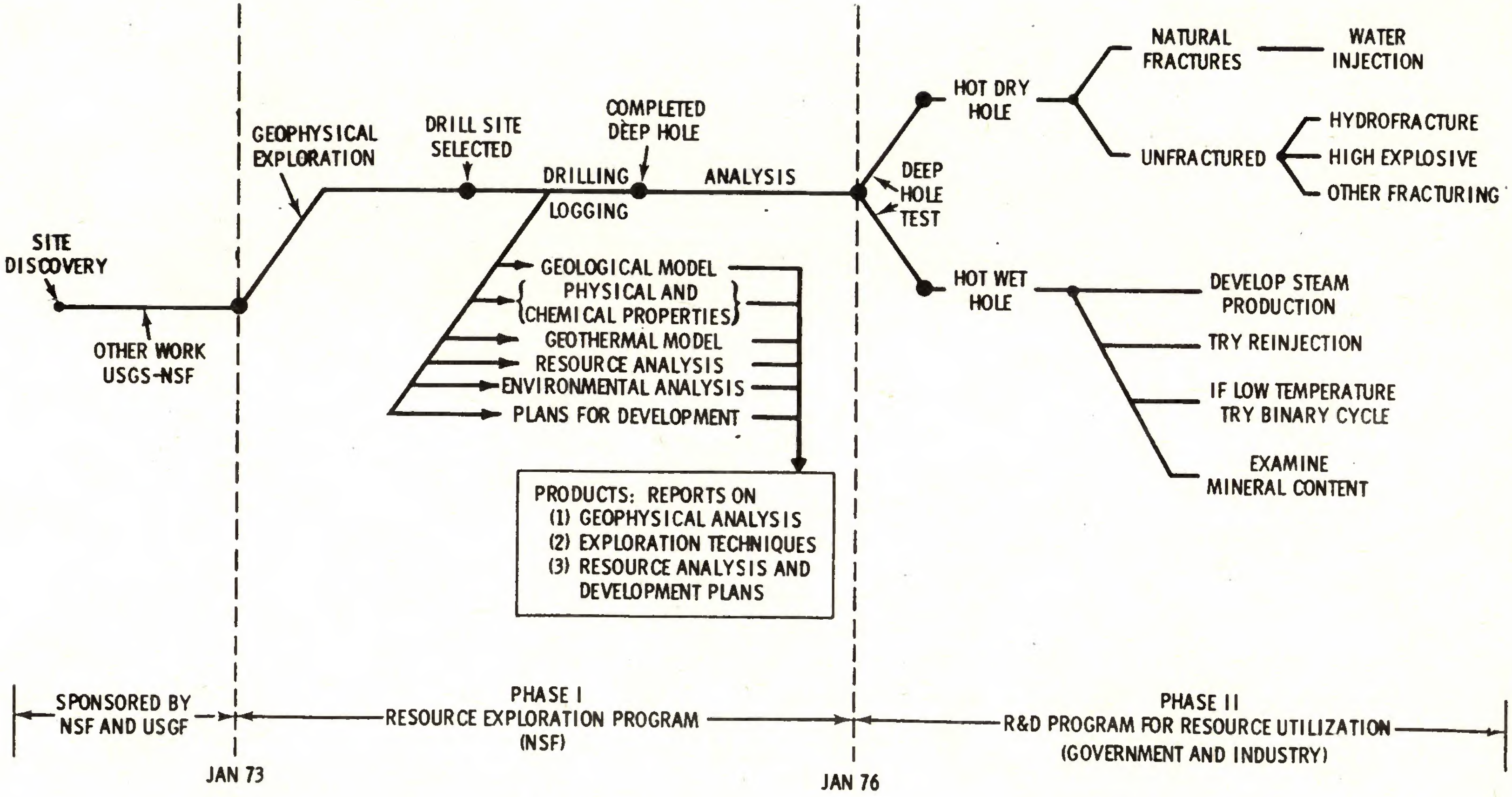

FIGURE 1. Planned Geothermal Resource Development Program

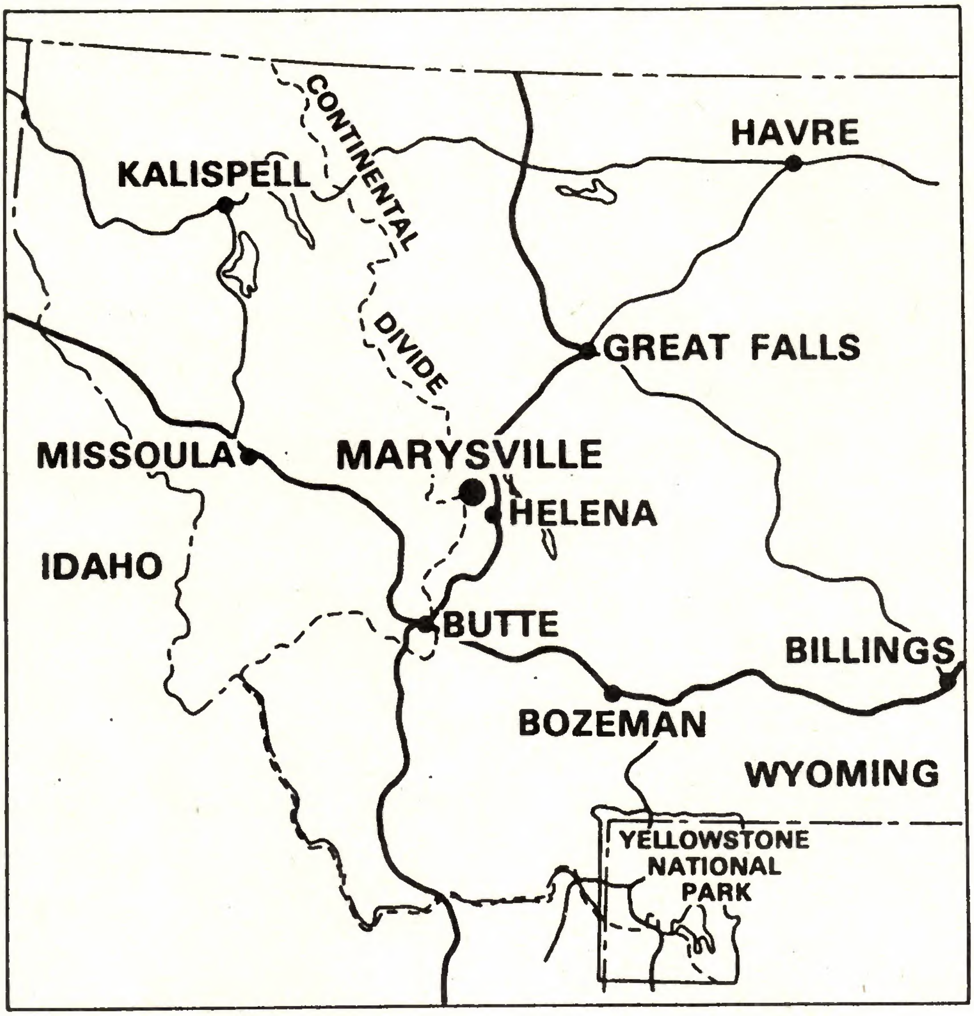

FIGURE 2. Index Map

The proposed well will be located in a geothermal anomaly near Marysville, Montana, an old gold mining town located about 20 air miles northwest of Helena. Measured heat flows in a local region near Marysville have been found to range from 3.1 to as high as 19.5 ucal/cm^2-sec,[1/] compared with a western Montana regional average of 1.9, and a world-wide average of 1.5. Although there is an obvious thermal anomaly, the nature of the source (dry and conductive or wet and convective) and its geophysical properties are unknown. Evidence that the anomaly consists of a dry granitic pluton 10,000 to 80,000 years old will require verification.

Details of the proposed well are shown in Figure 3. Plans are to drill to about 6,000 feet or to a limiting temperature (approximately 800° F.). The volume of cutting spoil will be about 500 cubic yards and will be disposed of as described below.

This well is typical of those employed elsewhere in geothermal fields, and not unlike wells drilled for oil and gas exploration and production. The drill rig to be employed will be of the "oil field variety" and will be capable of being moved to the site on several tractor-trailer rigs. A photograph of a drill rig similar to the one likely to be used is shown in Figure 4.

[1/] Blackwell, D. D., "Heat Flow Near Marysville, Montana", (abs.), Eos. Trans. American Geophysical Union, Vol. 51. p. 824, 1970.

The mitigating measures listed in this section for impacts upon the environment resulting from this project are included in the drilling contract. A copy of the contract is available for review in the Missoula District Office, Bureau of Land Management, and at Battelle-Northwest, Richland, Washington. Also, a copy will be maintained at the drill site after the project begins.

1. Site Preparation

Land Clearing - All trees (Douglas fir) within the drill pad will be felled, limbed to a top diameter of 2 inches, cut into firewood-length pieces, and stacked in a location to facilitate later hauling from the site. All slash which results from this clearing will be chipped and the chips disposed of by burying in a designated location. An estimated 70-80 trees are involved.

Soil - All soil and soil material will be carefully removed from all areas to be disturbed, and will be stockpiled and saved for later site restoration.

Earthwork - Earthwork will consist of moving about 5,000 cubic yards of earth for the purpose of leveling and is scheduled to begin April 15, 1974. The total site area is less than one acre. Large tailings mounds from old placer mining operations exist on the north end of the site. (See Figure 6.) Where practical these mounds will be leveled and the material used for the roads and parking. The drill

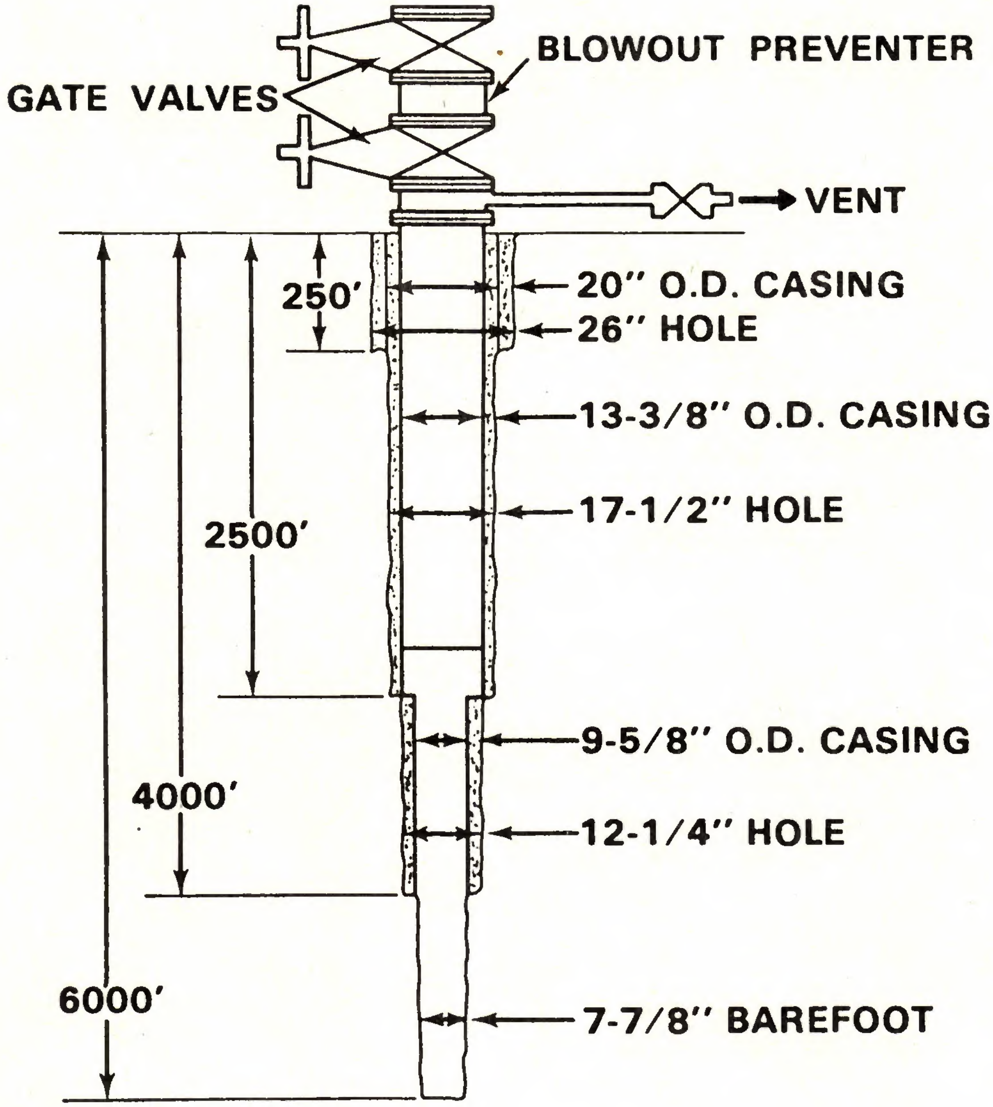

FIGURE 3. Deep Well Profile

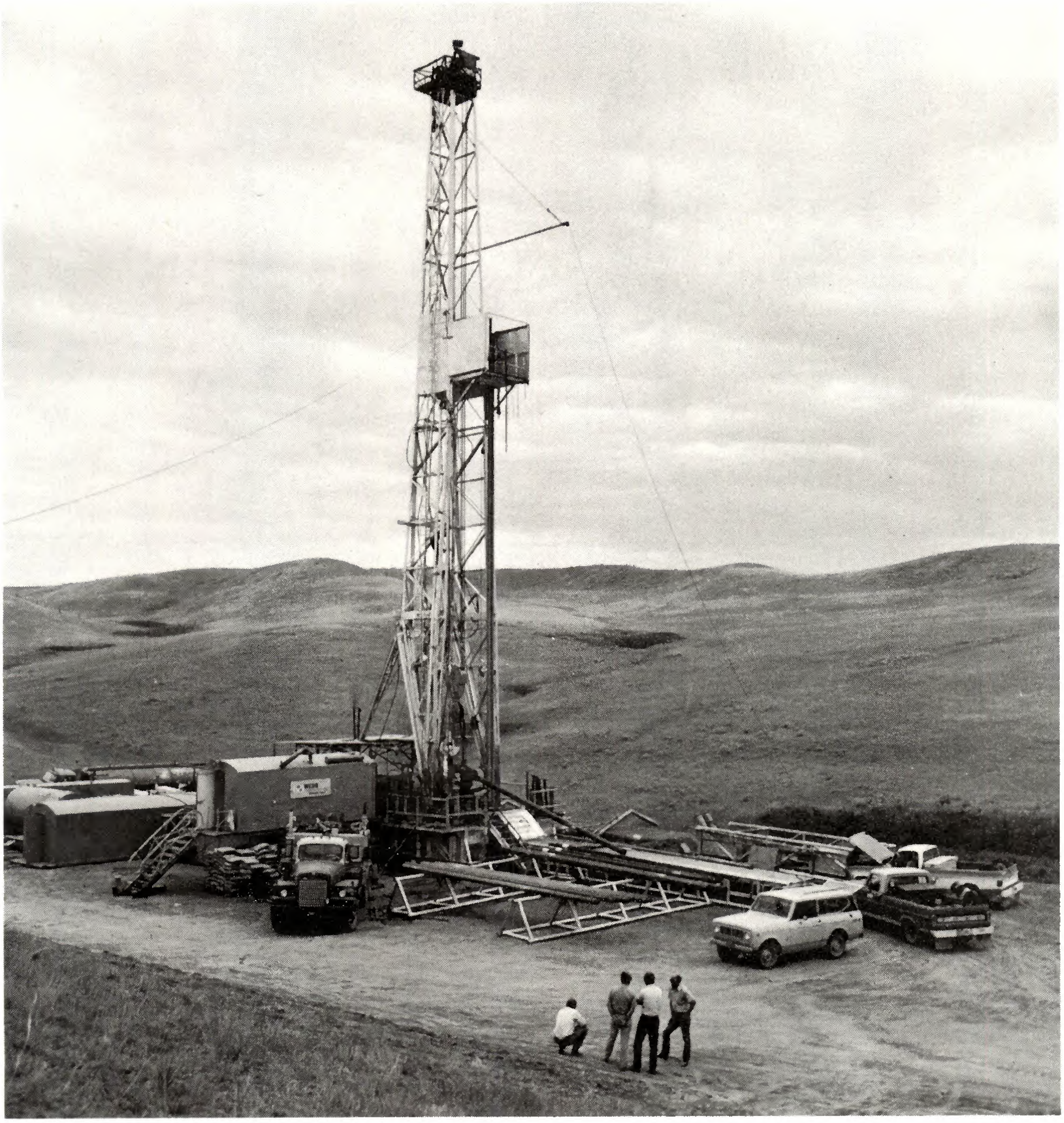

Figure 4. Drill rig on location. This rig is of the type likely to be used in Empire Creek. Note size of pad (leveled area), water tank truck partially hidden behind fuel storage tank in lower right. Also note cement truck and sacks of cement near dog house just left of derrick. Thirty three foot section of 7-7/8 inch pipe is being raised.

site will be sloped at 1-2% toward the mud sump and a berm will be provided between the service road and Empire Creek to control runoff.

Water Source and Storage - Water for the drilling operation will be obtained from one or more water wells to be drilled at the site. Mr. Wesley Lindsay, President of the Montana Water Well Drillers Association, visited the site and believes that the required 60 gpm of water could probably be obtained from one to three wells at a depth of about 100 feet. An application for an interim water permit for groundwater use of 60 gpm has been made to the Montana Department of Natural Resources, Water Resources Division. The water will be stored in a 1,000-barrel tank at the site. Daily usage during drilling is expected to be 500-1,000 barrels. The water wells will be drilled early in the site preparation stage, but not prior to installation of the service road culverts. All cuttings and silt laden water produced from drilling the water wells will be collected in tanks or similar vessels and disposed of by burying or dumping in designated site. Two alternatives exist to the pumping of groundwater: (a) water could be trucked to the site, and (b) surface water from Empire Creek could be stored in a reservoir. Such a reservoir would require a 10-foot earthen dam and rock-lined spillway capable of storing 10-15 acre feet, and the reservoir would cover about 2 acres immediately above the parking area. In the event that

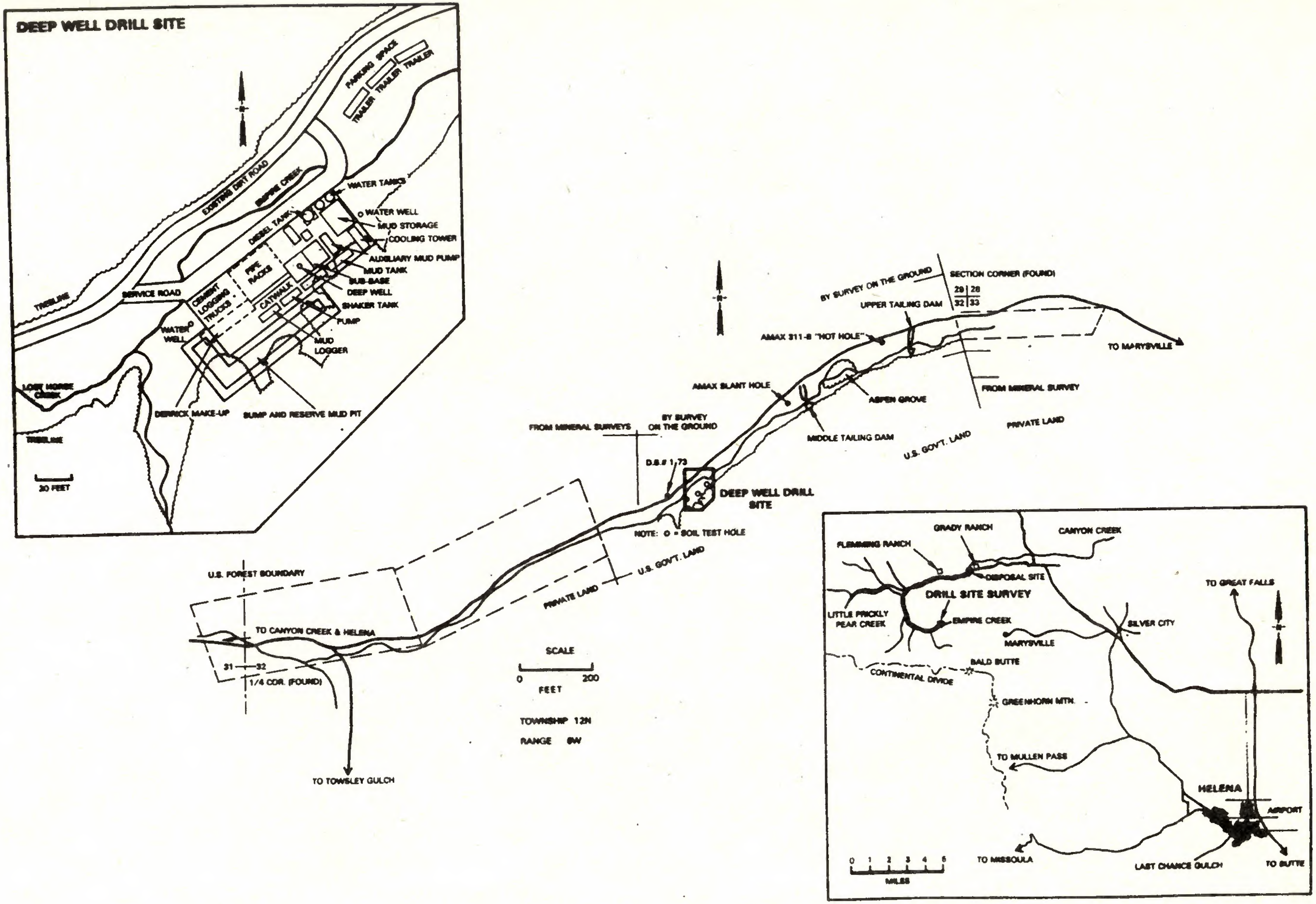

FIGURE 5. Maps of Drill Site and Vicinity

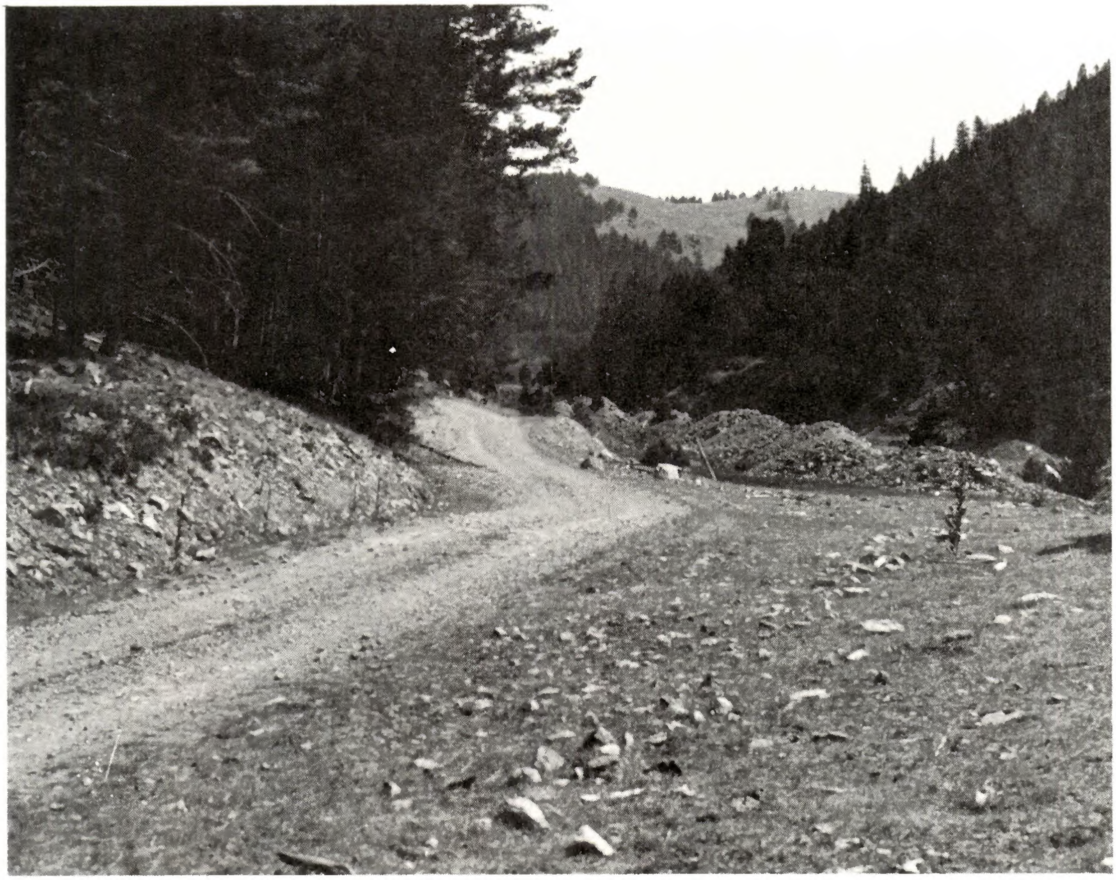

Figure 6. Photograph of drill site looking east up Empire Creek. Note two rows of placer tailings, road, and nature of vegetation. The service road will enter the drill site near the center of the photo. The drill pad will occupy all of the area now covered by the dredge tailings in this photo.

adequate groundwater is not available, the surface water will be impounded. Trucking will be used only as a last resort because of the additional dust and accident hazards associated with frequent trips of a large tank truck. Pumping directly from Empire Creek was not considered because of the uncertainty surrounding water rights in this drainage. Water quality monitoring will be done during and after the drilling phase. This monitoring will begin in May, 1974, and will be continued throughout the life of the project.

Service Road - As seen in Figure 5, a crossing of Empire Creek both in and out of the work area will be necessary. The size of galvanized steel culvert pipe needed will be selected after the drainage area and runoff are calculated and will be of adequate size to pass spring runoff, but in no case will be smaller than 36-inch diameter. Fill for the entrance and exit roads will be taken from the gravel mounts nearby. Gravel and rock will be used where the fill is exposed to the creek's flow.

Drill Pad - The maximum area to be concreted for the drilling operation will be a 8 ft. by 8 ft. by 6 ft. drilling cellar. Tentative plans are to leave this in place and fill it up level with the graded surrounding area, if abandoned. The deep well drilling is scheduled to start June 1, 1974.

Diesel Fuel - The contract specifications will require the drilling contractor to provide a minimum of 2,500 gallons of secure diesel fuel storage on site. An adequate berm area will be provided surrounding this tank to contain the entire volume if accidentally spilled plus an allowance for precipitation. The pit will be vinyl-lined to prevent any spillage from entering the groundwater. Volume of fill material above the impervious layer will be at least twice the tank volume or 22 yards. The hazard of a fuel truck accident is recognized and therefore, the fuel supplier will be required to provide emergency cleanup services on a standby basis, to be used in case of an accident.

Settling Pond - The settling pond or mud sump will be 8 feet deep, and will serve as a depository for the solid cuttings from the drilling and as a reserve mud pit. This pit will provide ample volume to hold the total volume of drill cuttings and drilling muds (about 500 yards) and still provide sufficient reserve mud sump volume. The cuttings should accumulate as "chunks" and thickened slurry to a depth of about 2 feet in the sump. With the expected high drilling temperatures, flashing to steam of the water portion of the drilling fluid during cooling will tend to minimize the volumes of waste fluids. Percolation of fluids into Empire Creek is not expected since the drilling mud ingredients are designed fundamentally to seal off porous formations. Therefore, it is felt that no lining of the settling pond is indicated. The mud ingredients, basically bentonites, lignites, barites, and non-ionic surfactants, are natural materials, and are not expected to degrade under the temperature predicted. Thus, leaching of any foreign materials into Empire Creek is not likely (even if fluids would reach the drainage).

The mud sump will be bermed to exclude entry of any surface runoff except that from the drill pad itself.

The recommended final disposition of the spoil (solid, viscous slurry and liquids, if any) is to bury them in the settling pond. These spoils may have to be dried for a period of time and mixed with existing natural material prior to being buried.

If drilling condition require use of air as a drilling medium, in lieu of drilling mud, the reserve pit shall be kept full of water and shall be used as a scrubber. The return air line shall be carried into the pit and through a sparger a sufficient distance below the water surface to remove all cuttings and dust from the effluent air. As cuttings accumulate in the sump, they shall be distributed so as to maintain efficient scrubbing action along the length of the sparger. The pit-scrubber will also serve as a muffler to reduce the noist level.

AC power supply may be required at the drill site, if so, a power line would have to be constructed from the Empire Mine to the site a distance of approximately one mile. Construction of this line can be accomplished without cutting of timber or construction of new roads.

Waste Disposal - Human waste disposal will be handled by chemical facilities using trailer-mounted holding tanks and septic service pickup. Litter and other garbage will similarly be hauled from the site to approved waste disposal sites.

Parking Area - Figure 5 shows an area allotted for parking. This is at the upstream or east end of the site and was selected to avoid felling any more trees than necessary. Visitor parking will be provided in this area. Additional parking is available in various parts of the area assigned to well-cementing and well-logging trucks. Roads and parking areas will be sprayed with water as needed to control dust.

Archaeological Values - A preliminary archaeological survey will be conducted in and around the site prior to any disturbance. This survey will be conducted by the University of Montana, Anthropology Department, and is scheduled for April 1974.

Visitor Management and Policing - Due to much local interest in this geothermal project, visitors are expected daily. To provide for their interest and safety, a small viewing platform with descriptive signs will be placed on the hillside to the north of the drill site near the visitor parking area.

A barbwire fence with gates on the service road will encircle the working area to keep visitors, cattle, and wildlife out of the danger areas. The fence will enclose the settling pond to keep the cattle from drinking the drilling fluids or falling into the pit. Contractor personnel will be responsible for daily policing of both the drillsite and the visitor site to remove cans, debris, etc.; and to maintain a clean area.

Safety and Fire Protection - Fire protection and prevention facilities at the site will comply with the regulations of the Bureau of Land Management and the Forest Service for field operations of this type. The standard safety procedures established in the oil and gas industry for deep drilling operations will be followed also. Radio-telephone communications to the BLM Area Office in Helena will be available at the site while work is in progress. During August of 1973, fire danger in this area was exceptionally high and all unnecessary operations and travel were prevented. Should this situation reoccur in 1974, contractors will comply with the requests of the cognizant federal fire control agencies.

Safety procedures for personnel and equipment that are standard in the drilling industry will be followed by all contractors. The drilling supervisor will have the authority and responsibility to enforce these practices.

Although it is considered highly improbable from the present geologic data, steam could be encountered in the drilling operation. The drilling rig will be equipped with a blowout preventer to ensure that any such steam would be kept under control. In the event that steam should be encountered, analysis of the steam will be made for chemical and gaseous content and it will then be capped off.

2. Site Abandonment

In the event that the geothermal resource does not warrant further development and the decision is made to abandon the site, standard abandonment procedures used by the oil and gas industry will be followed. The concrete drill pad and the well casing will remain in place. Any soil contaminated with diesel oil will be removed and transported to an approved disposal site as will other man-made residue originating from the project. The sump and reserve mud pit will be filled and the land leveled. The topsoil will be replaced, the area will be revegetated using mulch, fertilizer and irrigation, if and where needed. The culverts will be removed and the areas that have been compacted and or graveled will be scarified before revegetating. The fence will be left surrounding the drill pad.

B. Alternatives

The alternatives to the planned deep-well are limited. The following alternatives are considered:

1. No action
2. Selection of alternate site

The alternative of not drilling the well has little merit since the potential of the geothermal energy resource will remain unknown if basic research such as that described here is not accomplished. At the present time, geothermal energy may be of considerably less impact on the environment than other common sources.

Location of the hole is limited by the location of the underlying anomaly. From surface and near-surface measurements made by Dr. David Blackwell of Southern Methodist University during the summers of 1969-1973, it is apparent that the selected site is near the center of the anomaly. Some of Dr. Blackwell's work is included in Appendix A for reference.

While there are other possible drilling sites, they all have serious drawbacks. They either involve more timber cutting or more earth moving and road construction than the present site. In addition, most sites would require relocation of Empire Creek; but by a careful layout of the site (see Figure 5) it has been possible to avoid this relocation at the present drilling site. Any site not located on the Empire Creek bottom would require severe cutting and filling of the steep mountain sides, causing much greater impact than could be expected at the planned site.

III. DESCRIPTION OF THE EXISTING ENVIRONMENT

A. Non-Living Components

1. Land

The drill site is situated in the valley of Empire Creek just east of the Continental Divide. Empire Creek is a small tributary of Prickly Pear Creek. The valley of Empire Creek is narrow and has fairly steep lower slopes which become more gentle near the side ridges. Topography of the area is typical of a rejuvenated mature surface, where the high ridges represent the old erosion surface. Refer to Figure 6 which is a view looking down Empire Creek to the west.

Elevation of the drill site is about 5,200 feet. Mount Belmont on the Continental Divide about 3 miles east of the site rises to 7,330 feet.

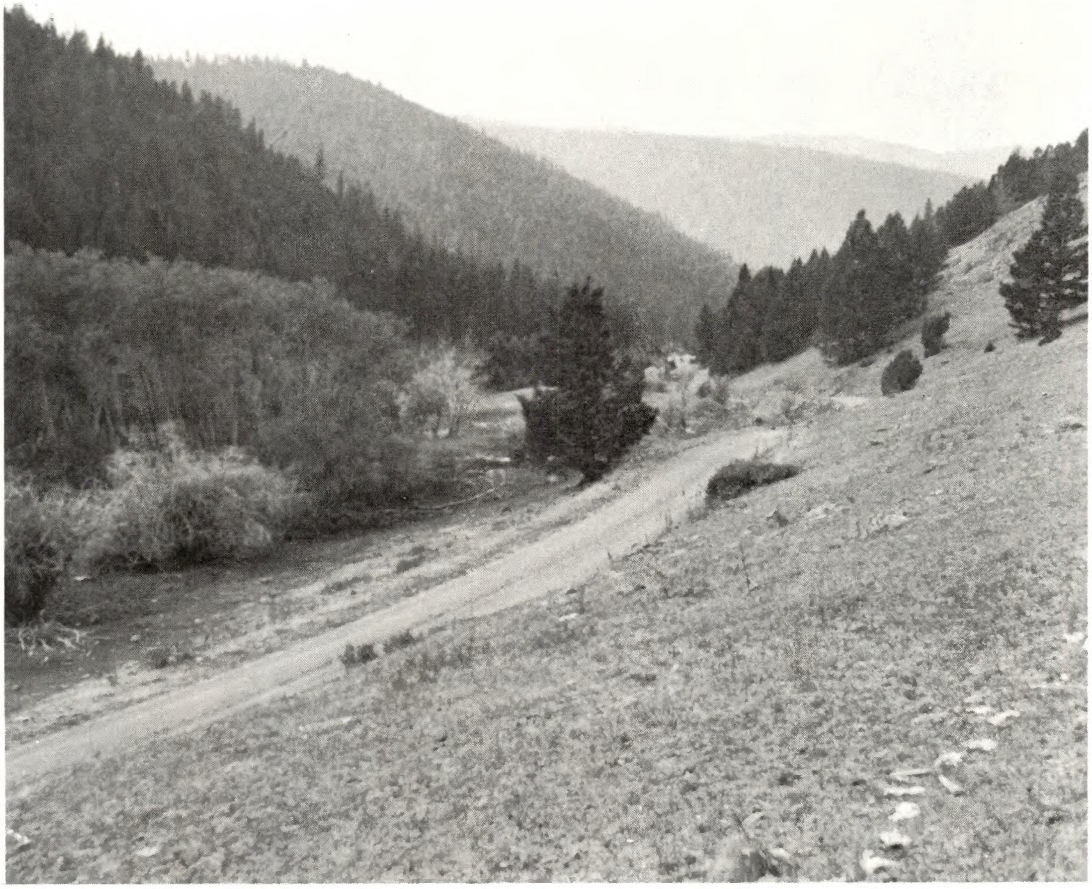

Figure 7. Photograph of drill site looking west down Empire Creek. The drill site is in the valley bottom in the distance. The dredge tailings appear white in the valley bottom.

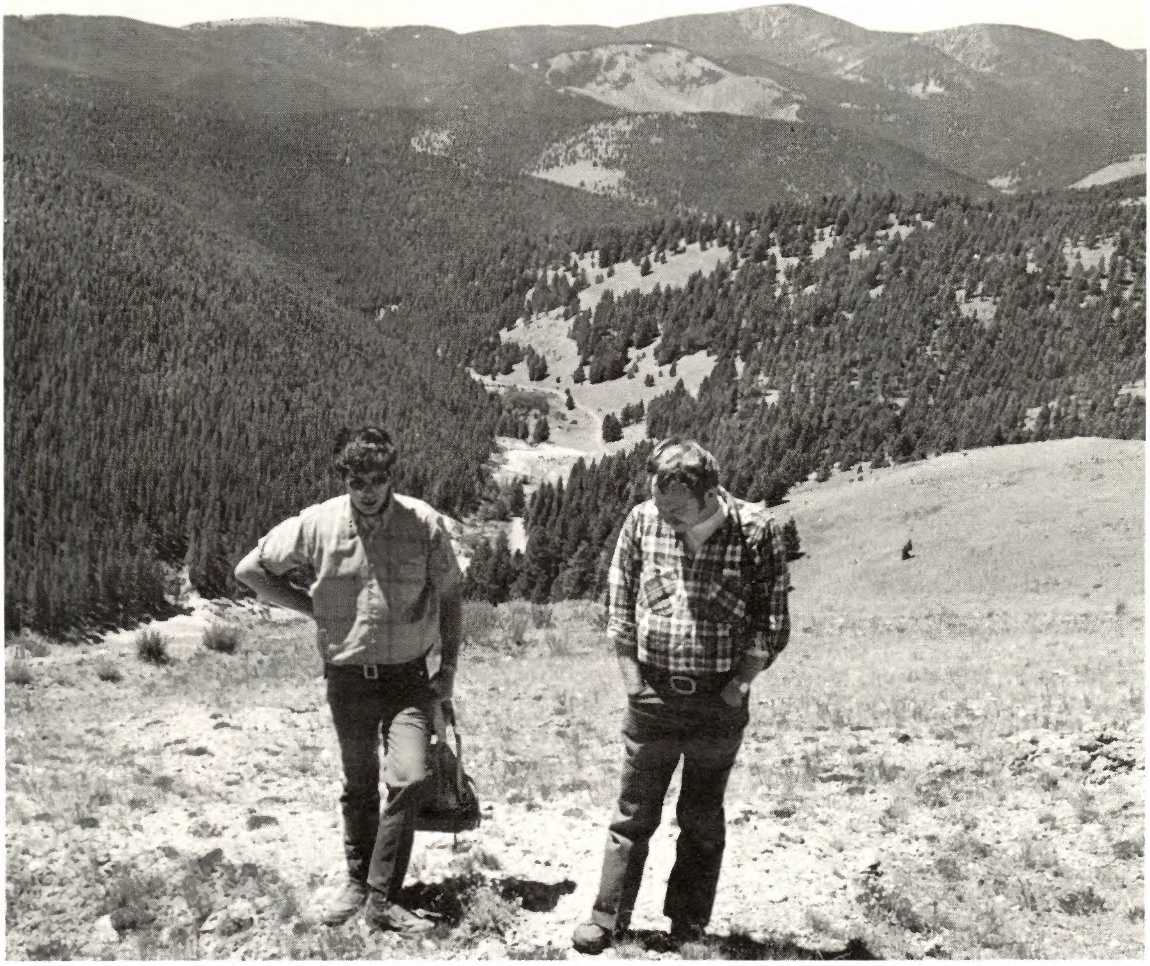

Figure 8. View of Empire Creek drainage looking west down the creek toward the drill site which is in the bottom of the creek where the road disappears into the timber. The distant skyline is the Continental Divide. Mill tailings from the Empire Mill appear white in the valley bottom. Lost Horse Creek and Prickly Pear Creek flow from left to right in the upper right of photo.

Bedrock geology of the Marysville area is described in detail in Appendix A, and in the Preliminary Report dated November 12, 1973.

Bedrock exposed on the surface at the drill site is Empire Shale, a dense, blocky, fracturing argillite. Lying below the Empire Shale is the Helena Limestone (actually a dolomite, high in silica) which in many areas has been metamorphosed to a dense hornfels. The Helena is not exposed at the drill site, but its outcrop surrounds the Empire outcrop. A tertiary intrusive occurs in Empire Creek just above (east of) the drill site. This stock, a Cenozoic quartz porphyry is not exposed at the surface but was encountered in drill holes just below the surface.

High angle normal faults are common in the area. No major movement along faults near the site is known. Microseismic observations indicate the general area between Marysville and Helena to be experiencing frequent events. No slumping or recent geologic hazards in or near the site are known.

Soils of the mountain slopes surrounding the drill site are shallow, gravelly and rocky loam and probably belong to the gray wooded and brown podzolic soil groups.

Soils of Empire Creek valley have been modified by finely ground concentrator tailings from the Empire Mill and by local small-scale placer mining in Empire Creek. Remnants of at least 3 tailings ponds, of two ages, occur in Empire Creek above the drill site. Considerable erosion of these concentrator tailings ponds and the dams that form them has occurred with redeposition of the tailings downstream. (See the photo of Figure 9.) The dredge tailings occur on either side of Empire Creek through the drill site (see photo of Figure 6), and consist of an unsorted mixture of alluvium with a portion of the finer material having been removed.

The land is currently being used for mineral exploration, livestock grazing, and public recreation such as sightseeing, hunting, etc.

2. Air

Two regional air movement patterns generally influence this area: Pacific fronts commonly accompanied by moist cool air move from the Pacific Coast westward, cross the Continental Divide and out onto the Plains; cold Arctic fronts move out of Canada, and push down along the eastern front of the Rocky Mountains. Dirunal convection currents caused by solar heating are common following sunrise and sunset. During periods of general westerly air flow over the Continental Divide, the orographic currents are modified and erratic air currents are produced along and just east of the divide where the drill site is located.

Mean annual air temperature at Marysville is about 41° F. with extremes ranging from -22° F. to 91° F. Average number of frost-free days is estimated at 90. Diurnal temperature variations measured at the drill site in September, 1973 were in the order of 11° C. to 14° C. (19° F. to 25° F.) Air temperature-altitude gradients are about -1.75° C. (3+° F.)/ 1,000 feet.

No air quality data are available for this area. However, particulate matter concentrations have not been observed. Minor particulate matter and hydrocarbons in the upper atmosphere caused by logging slash burning have been noted; however, this condition was not persistent. The only possible source of sulfur oxides would be the East Helena Reduction Works, and it is extremely remote that this plant's emission could reach the area.

3. Water

Annual precipitation averages about 19 inches with the wettest periods being January and June. (See Table 1.)

Empire Creek is a perennial stream with a moderate gradient of about 300 feet/mile in the vicinity of the drill site. The banks and stream bed are composed of old compacted tailings with the majority of the stream substrate being compacted silt. The creek flow is just a few cubic feet/second. (See photos of figures 9 and 10.)

Little is known of the ground water situation in this area. Several small springs are found in the headwaters of Empire Creek, and ground water occurs in many of the underground mine workings. It is believed that water for the drilling operation can be obtained from the water table by drilling 1 or 2 wells. Water flows from a diamond drill hole just east of the drill site. Temperature of this water is about 22° C. compared with a summertime temperature of nearby Empire Creek of about 14° C.

Geophysical data (electrical resistivity) indicate that rocks between 600 and 1,000 meters in depth are relatively non-porous and contain relatively little mobile water.

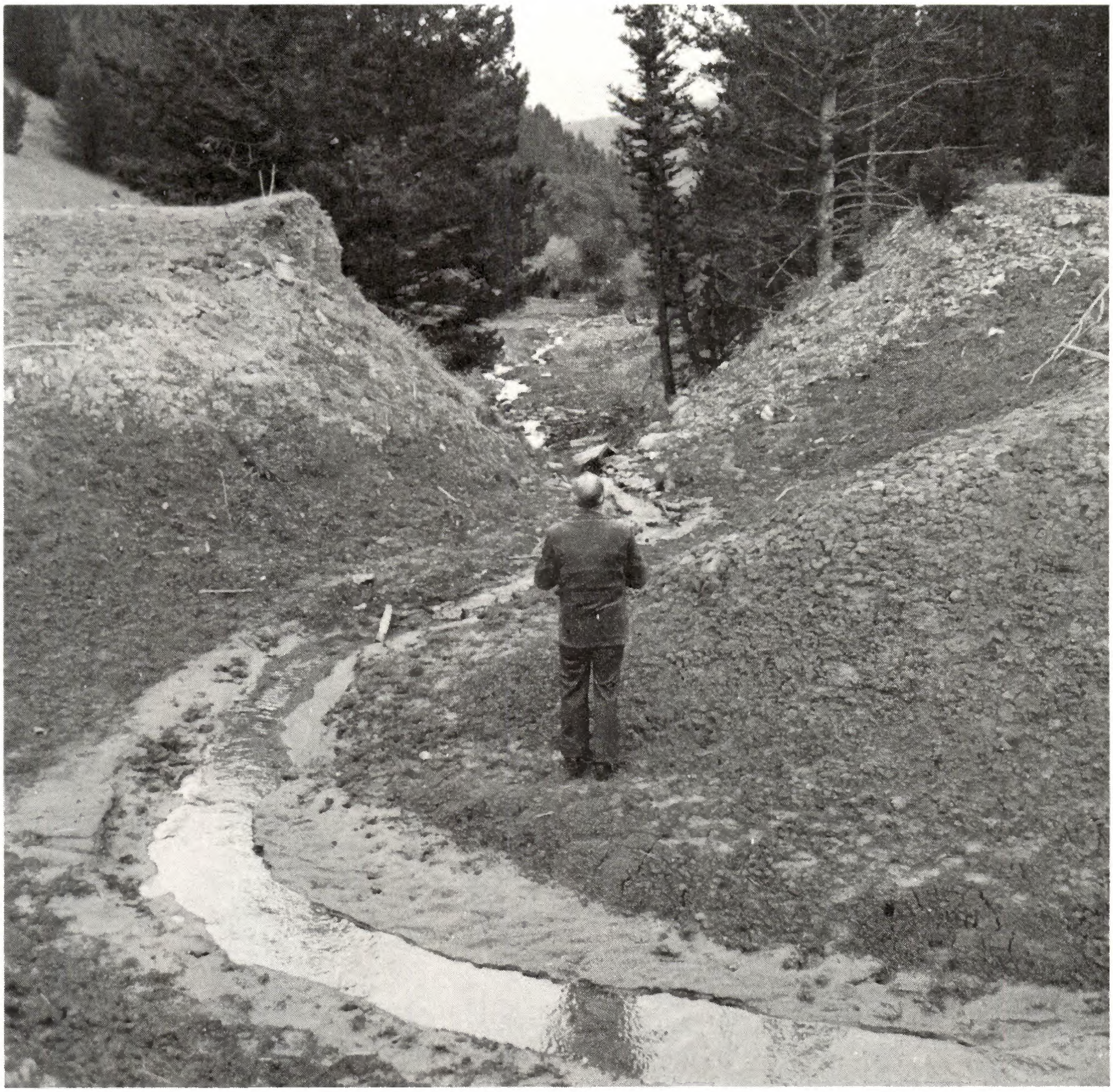

Figure 9. View looking down Empire Creek from old washed out concentrator tailings dam. This photo point is just upstream from the drill site. Note high water mark in the tailings which resulted from an exceptionally heavy rain storm just prior to the date of this photo.

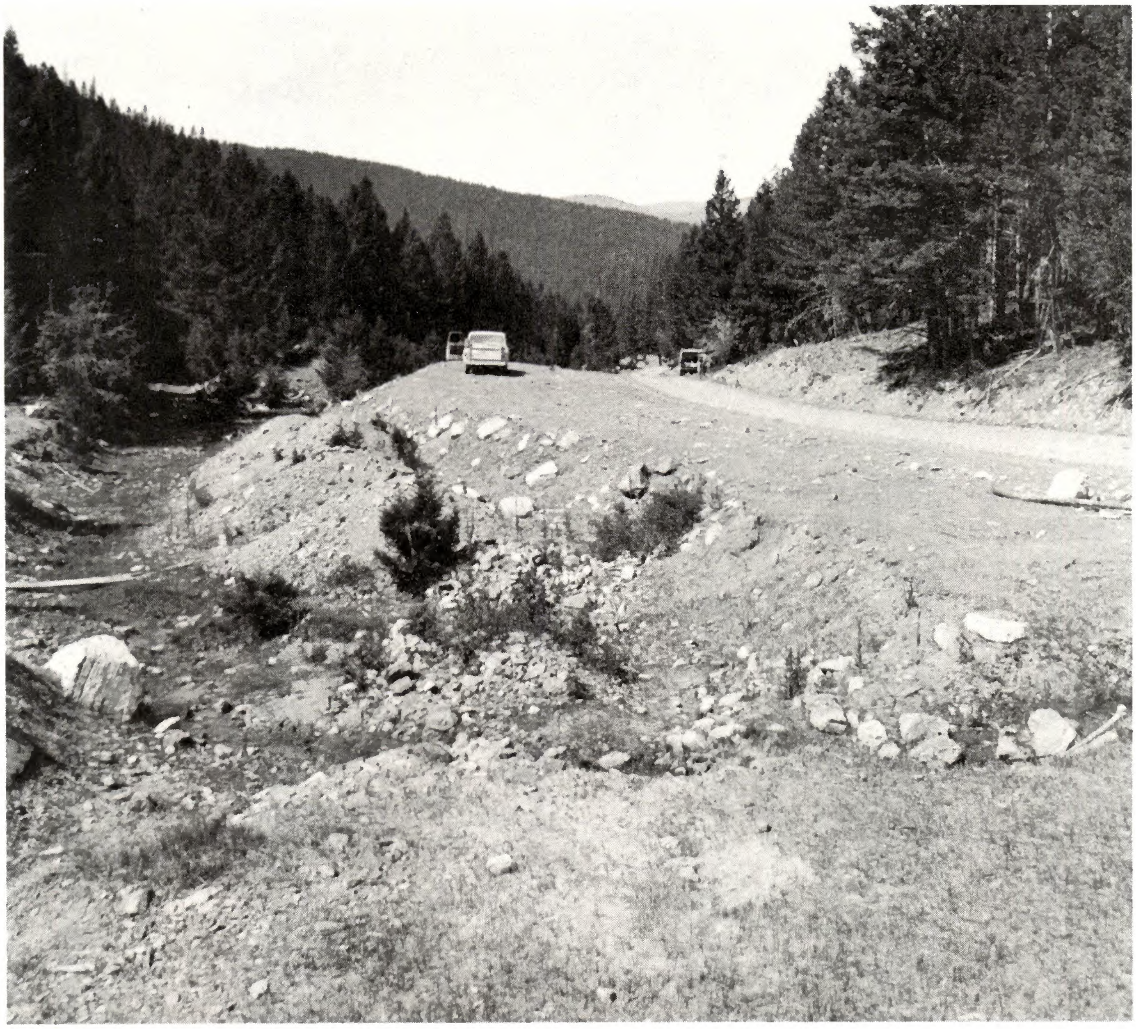

Figure 10. Photograph of Empire Creek just below the drill site. Note character of stream banks and bed and magnitude of flow. The service road will cross Empire Creek just to the right of the small juniper.

TABLE 1

Average Precipitation at Marysville, Montana

Month	Precipitation
January	2.35
February	.76
March	1.27
April	1.47
May	1.92
June	4.29
July	1.01
August	.62
September	1.95
October	1.18
November	1.26
December	1.32
Annual	19.40

The average was computed from U. S. Weather Bureau measurements made at Marysville No. 3 for years 1968, 1969 and 1970.

B. Living Components

1. Plants

a. Aquatic - No aquatic plants were noted other than equisetum, a vascular plant associated with moist sites. Phytoplankton are present, however, no identification was attempted.

b. Terrestrial - The vegetation is a mosiac of Douglas fir habitat types, open bunch grass parks and narrow stream bottom meadows. Years of heavy grazing by domestic animals have created a bluegrass (Poa spp.) sod in these stream bottom meadows.

2. Animals

a. Aquatic - Empire Creek does not support a fisheries nor does it have any resident aquatic mammals or waterfowl.

The high silt substrate probably excludes most of the invertebrates associated with typical gravel and sand creek types. The invertebrates that would be found in Empire Creek in the drill site area are probably annelids and other invertebrates typical of silty substrates.

b. Terrestrial - A variety of both game and non-game birds frequent the area at various times of the year. Small mammal life includes small rodents, bobcats, fox, coyotes, and rabbits. Deer, elk, and bear are also found in the Empire Creek Drainage.

Empire Creek is in State Hunting District #443, which in 1973 was open for hunting for antlered bull elk and mule and white tail deer from October 21 through November 25. Hunter success for elk is 13% and for deer is 61%.

C. Ecological Interrelationships

Cutthroat trout (Salmo clarki) habitat is usually associated with mountainous streams with clear, cool running water. These creeks are typically of high quality and relatively silt free. The ecological interrelationship of concern is the dependence of aquatic invertebrates and salmonid fishes on high quality water.

As has been pointed out, suspended sediment is the only adverse aquatic impact of any concern in this project and in particular the downstream fisheries of which Empire Creek is a tributary. It should be pointed out at this time that the chances of sediment being a detrimental problem to downstream fisheries are minimal, however, the fact that sediment other than that which is normally encountered in Empire Creek warrants a discussion of the interrelationship in this aquatic habitat.

The nymph stages of semi-aquatic, insects are of great importance in the food chains of cold water fishes. Phytoplankton (algae) convert minerals, sunlight, water, etc. into organic plant matter which is again converted by aquatic grazers (nymphs) to animal tissue with final utilization of aquatic invertebrates by carnivorous game fishes.

Aquatic insects (nymphs) require habitat composed of gravel and lose rubble with good water percolation and surface area for food production (algae) and anchorage of individual nymphs to the substrate. A high silt load, even short termed, can reduce the permeability of this habitat with resulting loss of both algae and aquatic nymphs. Nymphs are not extremely mobil and fine silt with adhesive properties even in small quantities could have a smothering effect on these animals.

Sediment deposits can have two direct impacts on salmonid (trout) populations: (1) Mortality in mature fishes can result from gill abrasion from silt (2) the same porous substrate needed for aquatic insects is also essential for spawning areas.

Sediment deposits can simply reduce the porosity of the spawning areas removing them from production. Secondly, and many times not considered, is the loss of incubating salmonid eggs from smothering by fine silts.

Of particular interest is the presence of cutthroat trout (Salmo clarki) in Lost Horse Creek and there spring spawning behavior (May and June). Incubation of cutthroat eggs is dependent on water temperature, for example, at 50° incubation is approximately 30 days. We can expect Lost Horse to have incubating eggs present in it during the preliminary stages of site preparation of the project and it is during the period that situation could be critical.

D. Human Values

1. Landscape Character

The landscape of the area offers a pleasing view to the observer with a variety of form (topography), color (vegetation), and texture. High windswept ridges and densely forested slopes interlaced with numerous parks provide a congruous visual variety.

Human cultural processes, primarily mining and mineral processing and livestock grazing have altered the local landscape considerably. Much of this modification is considered to be inharmonious, or to create visual confusion, such as that produced by the placer mining tailings; however, historical aspects and pleasing visual form and color imparted by many of the old buildings is believed to create an accentuating element to the landscape.

2. Socio-Cultural Interests

No archaeological sites or values are known to exist within or near the drill site. Some nearby mine and concentrator buildings are of recent historical interest.

The proposed action is designed to explore a natural process and add scientific knowledge of the existing geothermal anomaly. Local attitudes concerning the proposed action could be described generally as curiosity and basic approval. These attitudes probably result from fairly intense publicity which has been given to the proposed action.

Recreation - The drilling site is located in a remote area, however, it is readily accessible to the general public. No recreational fishing is done in Empire Creek. By far, the two largest recreational activities in the area are hunting and sightseeing by tourists who come because of the old gold mining operation. The geothermal research project will not interrupt these recreational uses of the area. There are no developed public campgrounds, lakes, or recreation facilities within 10 miles of the site. There is no available estimate of the number of user days of recreation occurring in the area.

It is recognized that the Marysville area is steeped in mining tradition and that activities are now in progress to permanently preserve some of the buildings and remnants of the gold-mining days. The focus of these activities is on Marysville itself because of the many old buildings concentrated there. The geothermal project is about 3 air miles over the 7,000-foot Mount Belmont from Marysville, and about 6 miles by road.

Because of the mountainous terrain it will be impossible to see or hear any activities of the geothermal project from Marysville. Hence, there will be no interference with any historical developments in Marysville.

IV. ENVIRONMENTAL IMPACTS OF THE PROPOSED ACTION

A. Anticipated Impacts

The most significant impact is expected from the noise and dust of traffic into the area. During the drilling period, a certain amount of noise and diesel fumes can be expected from the drilling rig. These impacts may disturb wildlife and livestock temporarily. This will be localized, though, in the immediate unpopulated area. Dust from vehicle traffic will be deposited on roadside vegetation, this is aesthetically unpleasing and may affect plant growth.

The impact on the environment from drilling this proposed test well should be minimal. About one acre of land will be stripped and leveled for an access road and work area during drilling. The nature of the construction lends itself to restoration of near natural conditions at the completion of the drilling program.

The behavioral patterns of some animals might possibly be altered with the introduction of men and machinery in the immediate vicinity, but this impact will be of short duration and will be minimal. Drilling of this well will have no effect on aquatic life in the lower parts of the creek if construction plans to prevent runoff are followed. No endangered species of wildlife will be affected by the project.

The visual impact of the drilling operation will be high, that is, the drill rig is unharmonious with the landscape. However, because the drill site is in a remote mountainous area the exposure to those who would find its presence displeasing is low.

The impact of drilling the water wells and pumping water from the water table is not fully known, but is not expected to be significant, and will obviously be of short duration.

Of the three possible methods of developing drilling water described earlier under Site Preparation, pumping from the water table will have the least environmental impact.

Access to the drill site is via public roads and it is assumed that the project will receive considerable attention of the news media. Therefore, a substantial number of curiosity seekers will be driving by the site.

Traffic should not be a problem except on the last mile of the Empire Gulch Road, where the road is a narrow single lane trail with few turnouts.

There is a potential for silting of Empire Creek. It is doubtful that any sediment load will reach Lost Horse Creek, however, if it does, there could be an adverse impact on the fish population. The degree of impact would depend on the amount of sediment involved.

In leveling the area, several large mounds of rock and gravel, left from placer mining, will be removed. If the site is abandoned, this level area will be available for vegetative production.

B. Possible and Recommended Mitigating or Enhancing Measures

- Cover drill site area with rock and gravel. Sprinkle work area with water to control dust.
- If access roads become too dusty, control dust by sprinkling with water.

- Bus crews from Canyon Creek or Helena to help reduce dust, traffic and the need for a large employee parking area at drill site.
- Install culverts prior to well drilling (water) and spring runoff to minimize siltation from these construction activities.
- Whenever fill material must be placed next to Empire Creek, such material shall consist of clean placer tailings.

C. Residual Impacts

The residual impacts will be minimal if the site is abandoned after the well is drilled. However, if the well is successful, a proposal will be made for continued research. The environmental impacts of additional research operations in Empire Creek will have to be evaluated after the research proposal is designed (see figure 1).

The residual impacts will be minimal if the site is abandoned after drilling is completed. If the site is not abandoned, a primary residual impact will be the continued presence of the wellhead facilities (cellar, pipe, valves, etc.). If the site is not abandoned a series of secondary residual impacts related to continued research will occur; however, as explained in the introduction, these impacts will be anlyzed, if and when they become part of a firm proposed action.

V. RELATIONSHIP BETWEEN SHORT-TERM USE AND LONG-TERM PRODUCTIVITY

The shortage of power and oil in the country requires that every effort be made to find new energy sources. The drilling of this well will have a small effect on the short-term use of the land. The results of the research may provide data which could lead to the availability of a major new energy source in all the western states. While such long-term productivity is still in the future and of necessity speculative, the minor short-term impacts are acceptable. However, applications for geothermal leasing of adjacent national resource lands by large corporations are now on file with the BLM and if this project is successful, issuance of leases could have an impact on long-term productivity of the present ecosystem of this area.

VI. IRREVERSIBLE AND IRRETRIEVABLE COMMITMENTS OF RESOURCES

There are no irreversible and irretrievable commitments of resources involved other than the energy expanded to drill the well and possibly the pipe used to line the well.

VII. PERSONS, GROUPS, GOVERNMENT AGENCIES CONTACTED

A. NSF Advisory Board

The Board provides advice, peer review, and comment to the National Science Foundation Geothermal Program Manager on progress and direction of the project, and meets once or twice per year, or as requested by the NSF Program Manager. Following project reviews, Board members respond individually with letters to the NSF Program Manager who factors their advice into his decisions. Board members will be appointed for each review and composition of the Board will vary to match the peer review needs of the project as it progresses. The Board for the review of October 26, 1973 was:

Dr. Jesse Denton, Director
National Center for Energy
& Power Management
260 Towne Building
University of Pennsylvania
Philadelphia, PA 19174

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Manager Area Development
Montana Power Company
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Charles R. Draper
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Los Alamos, NM 87544

Lillian K. Stone
Environmental Review Officer
Office of Environmental
Projects Review
Department of the Interior
Room 5325
18th & C Streets
Washington, D.C. 20240

B. Congressional Testimony

Committee on Science and Astronautics
Subcommittee on Energy
Chairman: Mike McCormack
  Geothermal Energy Hearing, Sept. 11
  Testimony by W. R. McSpadden

  Geothermal Energy R&D Act, Feb. 11, 1974
  Testimony by D. D. Blackwell and W. R. McSpadden

C. Federal Agencies

	Contact	
Atomic Energy Commission Washington, D.C.	Gerald W. Johnson Anthony Ewing Lewis Werner	
Bureau of Land Management District Office, Missoula, MT	John Fields Robert Newman Carl Lind	Richard Betts David Pickett John Lovell
Environmental Protection Agency Region 8, Denver, CO San Francisco, CA	John Hardaway James W. Shaw Robert C. Scott	
National Science Foundation Washington, D.C.	Ritchie B. Coryell Jay Holmes	
Forest Service Helena Forest, Helena, MT	Wm. Taliaferro James Whipple	

Geological Survey Menlo Park, CA	L.J.P. Muffler

D. Montana State Agencies

	Contact
Office of Lt. Governor	Wm. Christiansen
Dept. of State Lands	Robert Rudio Robert Duncan
Dept. of Natural Resources & Conservation	Gary Wicks Ron Guse John Hug Judson Sweet Larry Jakub Lynn A. Brant Albert Tsao Don Chisholm Frank Culver Jim Holloran
Dept. of Fish & Game	James Posewitz Alan Wipperman
Dept. of Intergovernmental Relations	Frank McChesney Raymond Dominick C. R. Draper
Environmental Quality Council	Fletcher Newby Walter Enderlin Richard Klingler
Bureau of Mines & Geology	S. L. Groff Miller Hansen
Air Quality Bureau	Fred O. Gray
Montana Historical Society	Sam Gilluly Harriet Meloy

E. Universities and Research Laboratories

University of Montana	Gary Crosby
Montana State University	Robert Chadwick
Montana College of Mineral Science and Technology	Koehler Stout Frank Diebold Charles Wideman

Oregon State University	Lorin Davis James Welte
Yakima Valley College	Harold Jones
University of Pennsylvania	Jesse C. Denton
Stanford University	Henry J. Ramey
Los Alamos Scientific Laboratory	Morton Smith

F. Professional Society Presentations

Montana Professional Planners Association	Oct. 12, 1973
Society of Industrial and Applied Mathematics	Nov. 9, 1973
Professional Engineers of Oregon	Dec. 11, 1973
American Society of Mechanical Engineers	Feb. 6, 1974
Professional Engineers of Montana	Feb. 22, 1974
Institute of Electrical and Electronic Engineers	Feb. 13, 1974

G. Presentations to Civic and Community Organizations

Date	Organization	Place
July 24, 1973	Lions Club	Helena, MT
July 25, 1973	KFBB-TV	Great Falls, MT
Aug. 8, 1973	Rotary Club	Helena, MT
Aug. 9, 1973	Helena JC's	Helena, MT
Aug. 20, 1973	Kiwanis Club	Helena, MT
Sept. 11, 1973	Exchange Club	Butte, MT
Jan. 26, 1974	Lions Club	Moses Lake, WN
Feb. 27, 1974	BLM Geothermal Workshop	El Centro, CA

VIII. INTENSITY OF PUBLIC INTEREST

Because public interest is high, extensive news coverage of the Marysville Geothermal Project is being obtained. Approximately 100 releases have appeared in the Northwest newspapers although many are duplicates. In addition, TV interviews with the project scientists have occurred in Helena and Great Falls. In July, the NSF prepared a film on their geothermal projects, including the Marysville Project, which has been used over the national TV networks. All of the presentations listed in the above paragraphs were followed by question-and-answer sessions and in most cases there was extensive public participation. The public reaction to the project has been highly favorable.

IX. PARTICIPATING STAFF

An interdiscplinary team approach was used to prepare this report. Team members included the following persons:

John Burham	Battelle-Northwest
James Kuwada	Rogers Engineering
William McSpadden	Battelle-Northwest
William Templeton	Battelle-Northwest
Robert Newman, Mining Engineer	Bureau of Land Management
Robert Byars, Wildlife Tech.	Bureau of Land Management
Richard Betts, Surface Protection Spec.	Bureau of Land Management

X. RECOMMENDATIONS ON ENVIRONMENTAL STATEMENT

The proposal involves drilling a 6,000-foot well to investigate a geothermal anomaly of high heat flow. Access is provided by existing roads. Direct impacts of earthmoving and vegetal destruction are limited to the site which is approximately one acre in size. The potential exists for some short term pollution of Empire Creek.

Visual impact of the drill rig and noise and air pollution will be limited to the duration of the drilling operation. All of the impacts that will occur can either be mitigated or will be of such short duration that they were judged to be of minor importance. There is no evidence of public controversy although there is considerable public interest. It is our conclusion that the proposed action is not a major federal action and our recommendation is that an EIS is not required.

SIGNATURES

Robert H. Byars 3/14/74

Robert H. Byars, Wildlife Management Biologist

Robert D. Newman 3/14/74

Robert D. Newman, Mining Engineer

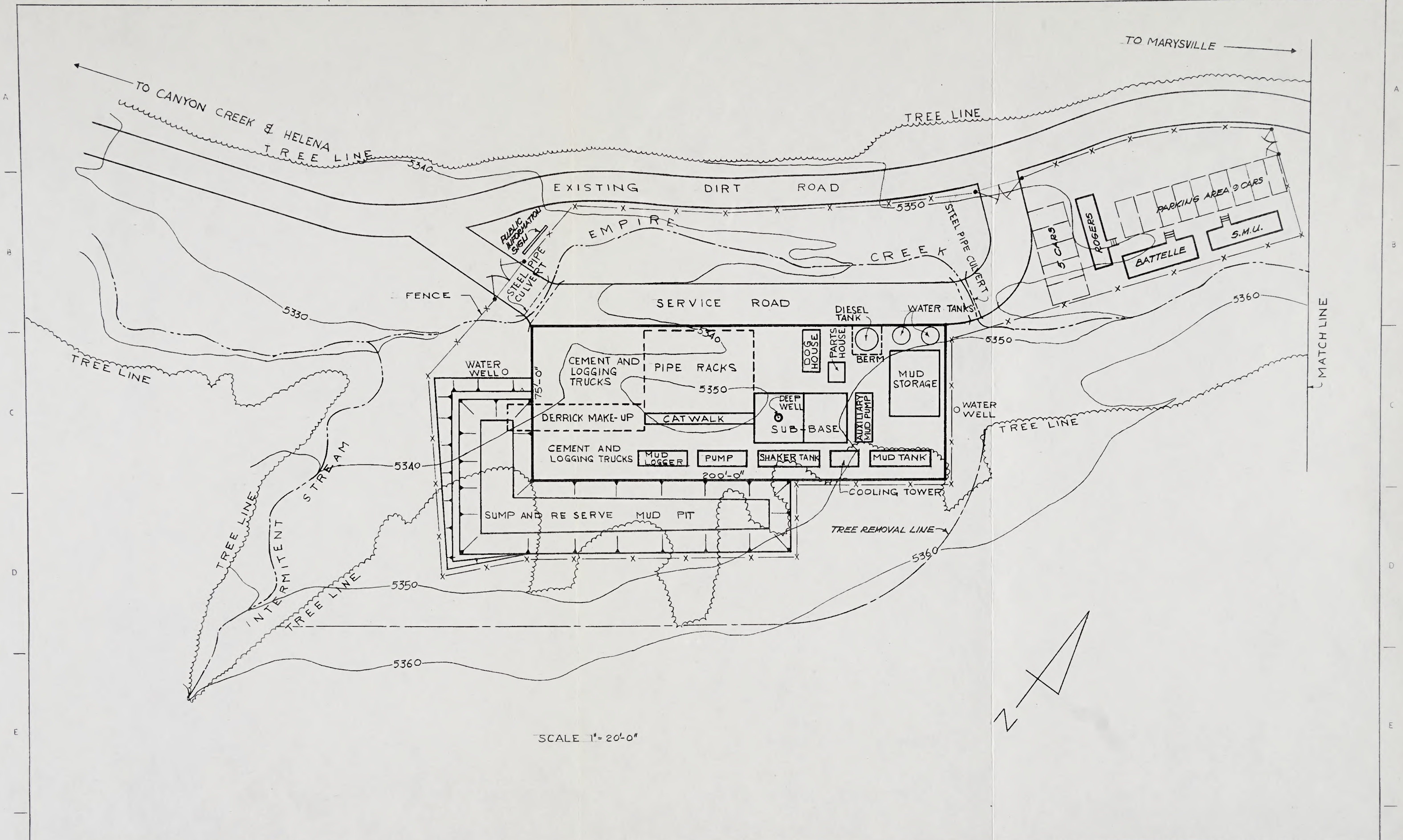
Richard E Betts 3/14/74

Richard E. Betts, Surface Protection Specialist

APPROVED:

Darrell C. Sall 3/14/74

Darrell C. Sall, Acting District Manager



SCALE 1" = 20'-0"

REFERENCE DRAWINGS	REV.	ZONE	DATE	REVISION	DR.	CHK.	APPR RECD	APPR	REV.	ZONE	DATE	REVISION	DR.	CHK.	APPR RECD	APPR
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ROGERS ENGINEERING CO., INC.
ENGINEERS - ARCHITECTS
16 BEALE STREET, SAN FRANCISCO, CALIF. 94 6

SCALE 1" 20'-0" DATE
DR. Hagd CHK. A.A. Jr. ENG. WFB APPROVED

BATTELLE PACIFIC NORTHWEST LABORATORIES
RICHLAND WASHINGTON
APPROVALS
DATE 2-28-74
DATE

MARYSVILLE GEOTHERMAL PROJECT
DEEP WELL DRILL SITE-PLAN

JOB No. S-73017
E-04-1004
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APPENDIX A

HEAT FLOW IN A "BLIND" GEOTHERMAL AREA NEAR MARYSVILLE, MONTANA

GEOPHYSICS, VOL. 38, NO. 5 (OCTOBER 1973), P. 941-956, 11 FIGS., 3 TABLES

HEAT FLOW IN A "BLIND" GEOTHERMAL AREA NEAR MARYSVILLE, MONTANA†

DAVID D. BLACKWELL* AND CZANG-GO BAAG‡

A unique geothermal area has been discovered during the course of a regional heat-flow study using holes drilled for mineral exploration. There are no surface manifestations of abnormal subsurface temperature in spite of the fact that at one locality a temperature of 58°C was measured at a depth of only 220 m. The area of anomalous heat flow straddles the Continental Divide near the old gold mining camp of Marysville, Mont. about 30 km northwest of Helena. Measured values of conducted heat flow range from 3.2 to 19.5 μcal/cm^2 sec. The immediate source of the high heat flow is either an unexposed reservoir of thermal fluids or a very shallow still-cooling magma chamber. At the present time the magma chamber model is preferred. The presence of additional similar areas in the western U. S. is suggested by the data from regional heat-flow studies. However, in most of the other areas only single anomalous heat-flow value is available, whereas at Marysville a region of several tens of km^2 is known to have abnormal heat-flow values. It is suggested that temperature measurements should be made in available drill holes deeper than 30 m in the high heat-flow regions of the western U. S. as an inexpensive way to explore for other "blind" geothermal reservoirs.

INTRODUCTION

During the course of an investigation of the regional heat-flow distribution in the northwestern U. S., Blackwell (1969) found unusually high values of conducted heat flow (averaging 6.5 μcal/cm^2 sec) at a locality about 30 km northwest of Helena, Mont., and 4.5 km west of the old gold mining camp of Marysville. Since that work, data have been obtained for an additional eleven holes in four other areas as much as 4 km from the original locality. In all the drill holes a conducted heat flow well in excess of the regional background is indicated. The highest value is 19.5 μcal/cm^2 sec and is the highest reported continental value of conducted heat flow measured outside a known geothermal area. The average gradient at that locality is 240°C/km in rock with a thermal conductivity of about 8 mcal/°C sec cm. In spite of extremely high gradients and resulting high temperatures at shallow depths, there are no surface manifestations of anomalous subsurface temperatures. The area appears to be unique in this respect and the object of this paper is to present the data and suggest some possible explanations for the high heat flow. The data have been mentioned briefly before (Blackwell, 1970), and the results reported here are preliminary in that additional work is in progress in the area. A gravity survey has been carried out, data are being reduced, and shallow drilling (<150 m) is in progress. However, the presently available data are believed to be of sufficient interest to justify publication at this time.

GEOLOGY

The geology of the Marysville stock, which outcrops over an area of about 5 km^2 around the town of Marysville, was the subject of a classic paper by Barrell (1907). From mine workings he

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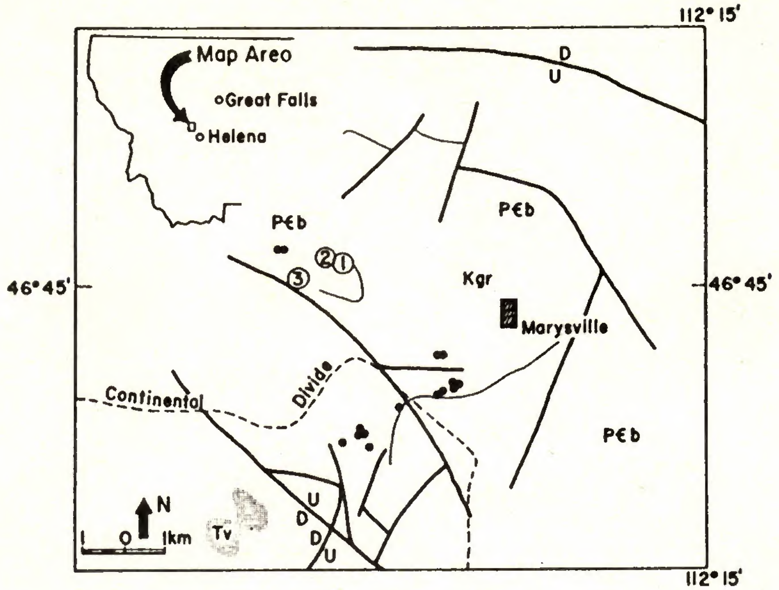

FIG. 1. Location map and generalized geologic map of the Marysville area (after Barrell, 1907; Ratcliffe, personal comm.). The heavy lines are the trace of faults. The symbols Kgr, *P€b*, and Tv stand for Cretaceous granodiorite (Marysville stock), Precambrian Belt Series, and Tertiary volcanics, respectively. Dikes and sills and a few small outcrops of Tv are not shown. Also not shown are Paleozoic sedimentary rocks lying unconformably above the Belt Series in the southwest corner of the map, and Quaternary alluvium in Little Prickly Pear Creek at the northwest edge of the map. The light line outside the Kgr indicates the limit of contact metamorphosed Belt rock surrounding the Marysville stock (Barrell, 1907). Locations of the drill holes are shown as solid dots. The location of the centers of spherical magma chambers are shown as circled numbers. The numbers correspond to the models shown in Figure 10.

developed detailed evidence supporting the stoping theory of magma emplacement. One of his figures is included in a widely used textbook on structural geology (Billings, 1954). More recently, aspects of the geology have been discussed by Knopf (1950), Mantei and Brownlow (1967), and Rostad (1969). M. Ratcliff (personal communication, 1971) has mapped parts of the Ellison 15 minutes, Canyon 7½ minutes and Granite Butte 7½ minutes quadrangles, including part of the area mapped by Barrell (1907). The mapping of Ratcliff covers the area of anomalous heat flow values discussed here.

The area location, generalized geologic information, and heat flow values are shown in Figure 1. Locations of the drill sites are shown on a generalized topographic map of the area in Figure 2. The bedrock in the area consists of Precambrian sedimentary rocks of the Belt Series (see Ross, 1963). The two formations outcropping most extensively in the area are Empire Shale and Helena Limestone. The shale is in most places a dense, blocky fracturing argillite. The limestone is actually a very impure limestone or dolomite with a silica content of about 33 percent (Knopf, 1950, p. 837). In much of the area the limestone has been transformed into a dense low porosity calc-silicate hornfels. To the southwest Paleozoic and Mesozoic sedimentary rocks onlap the Belt rocks.

The sedimentary rocks are cut by several ages of intrusive rocks, but the only exposed body of any size is the Marysville stock which, because of its proximity and similarity in composition to rocks of the Boulder batholith, was presumed to be of late Cretaceous age (Barrell, 1907; Knopf, 1950). According to a potassium-argon determination the age is 79 my (Baadsgaard et al, 1961) or about the age of older phases of the Boulder batholith and of the Elkhorn Mountains volcanics (Tilling et al, 1968). There are several suites of dikes and sills both pre- and post-emplacement of the Marysville stock. Several small outcrops of rhyolitic and dacitic volcanics occur in the area and more extensive outcrops occur to the north and south. These rocks may be correlatives of the Lowland Creek volcanics of

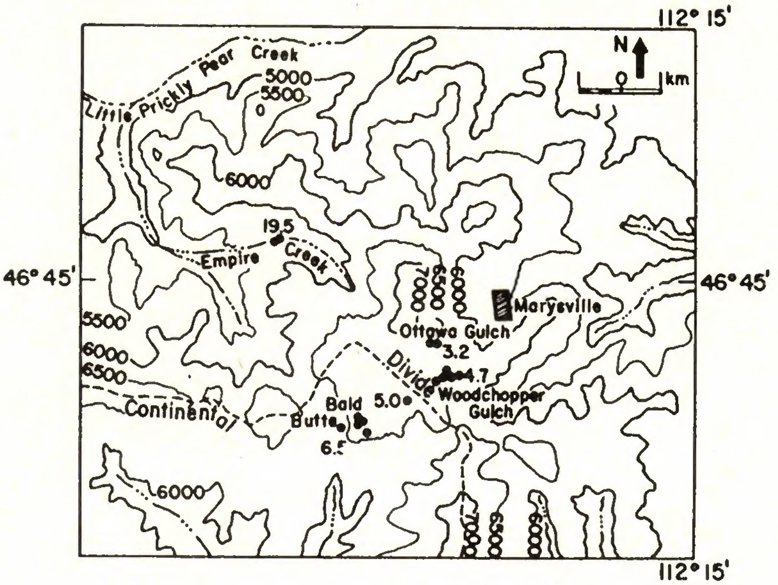

FIG. 2. Generalized topographic map of the Marysville area. The contour interval is 500 ft (152 m). Locations of measured drill holes are shown as solid dots. Heat flow value for each locality is also shown. Units of heat flow are μcal/cm^2 sec.

the Boulder batholith region which are Eocene (49 my) in age (Smedes and Thomas, 1965). However, Melson (1971) reported collection of a flora of probable Oligocene age from silt-stone beds in lavas near Little Prickly Pear Creek, just north of the Marysville district. In addition, drill holes at Empire Creek and Bald Butte cut small quartz porphyry stocks which have, respectively, little or no surface expression. The age of these intrusive rocks is Tertiary. The Bald Butte intrusive has been dated by potassium-argon techniques at 48 my (Rostad, 1969, and personal communication).

The Marysville stock is surrounded by a broad belt of contact metamorphosed sedimentary rocks (see Figure 1), and thus the stock may have a much greater subsurface extent than its present exposure would indicate, particularly to the west where the contact belt is 2 km or more wide, and where dikes and sills are most abundant in the Belt rocks. The stock occupies the center of a structural and topographic high perhaps caused by doming associated with emplacement of the stock. Most faults in the area are high angle faults, and some can be traced for several kilometers. Maximum displacements appear to be on the order of a few hundred feet.

HEAT FLOW

Temperature measurements are presented for 15 drill holes (Figures 1 and 2) forming a rough triangle with sides of 5.3, 4.7, and 2.5 km (enclosing an area of about 30 km^2). The holes were all drilled for mineral exploration; access to the holes and core for thermal conductivity measurements was kindly granted by the companies and individuals involved in the exploration. The two drill holes with the highest values of heat flow are in a valley occupied by Empire Creek. Five with intermediate heat-flow values are on a topographic feature called Bald Butte, and five with low (relative) heat-flow values are near a small valley called Woodchopper Gulch.

Data are also presented for two holes north of Ottawa Gulch and for a single hole on the Continental Divide between Woodchopper Gulch and Bald Butte. Heat-flow values calculated at these last two points are considered to be of low reliability, however. Several holes are quite shallow (<100 m), but because of high gradients, surface effects are quickly overcome and similar gradients are observed in adjacent drill holes (Table 1).

The largest uncertainty in the heat-flow determinations stems from the fact that many of the holes are inclined. Depths shown for all the in-

Table 1. Location, elevation, inclination, depth, thermal conductivity (K), gradient and heat flow. The depth range listed is the vertical depth below the surface for the inclined holes. The values shown immediately below averages are standard error

								Gradient		Heat Flow	
Locality	N. Lat.	W. Long.	Elev. meters	Inclination degrees	Depth range, meters	K mcal/cmsec°C	No[1]	Unc. °C/km	Corr. °C/km	Unc. µcal/cm^{2}sec	Corr.
Ottawa Gulch	46°44′	112°19′									
DDH — 1			1964	45	70-135	7.50	12	37.1	42.3	2.78	3.18
						0.25		0.3	0.4	0.11	
DDH — 2			1964	45	31-92	(7.50)		35.3	43.1	(2.7)	(3.2)
								0.4	0.5		
Mean Value											3.2
Woodchopper G.	46°44′	112°19′									
DDH— 3			1974	45	18-64	(7.48)		46.0	61.7	(3.4)	(4.6)
								1.1			
DDH — 4			1958	68	29-97	7.48	6	52.4	59.9	3.89	4.48
						0.45		1.1	1.8	0.31	
DDH — 5			1946	45	21-130			> 50.9	—	—	—
DDH — 6			1979	67	28-106	6.89	12	72.2	72.3	4.98	4.98
						0.26		0.3	0.3	0.21	
DDH — 7			1993	90	30-50	(7.06)[2]		49.4	49.7	(3.4)	(3.5)
								0.5	0.5		
Mean Value (DDH-4 and DDH-6)											4.7
Continental Div.	46°43′	112°19′									
DDH — 8			2076	48	30-82	(7.06)[2]		63.0	70.5	(4.45)	(5.0)
								0.9	1.0		
Bald Butte	46°43′	112°21′									
DDH — 9			2043	90	100-210	11.7	13	70.4	78.6	8.0	8.9
						0.8		2.1	2.3	0.2	
DDH — 10			2092	90	60-80			(65.5)			
DDH — 11			2001	70	52-281	8.42	13	72.5	80.5	6.38	7.10
						0.36		0.5	0.9	.07	
DDH — 12			2043	90	100-280	9.02	13	72.5	79.9	6.68	7.35
						0.58		1.6	1.5	0.15	
DDH — 13			1921	55	140-250	7.28	8	83.9	81.9	6.27	6.12
						0.62		1.2	1.1	0.16	
Mean Value						8.08[3]	27		80.2		6.5
						0.28			0.7		
Empire Creek	46°45′	112°22′									
DDH — 14			1654	45	88-164	16.4	7	83.7	74.8	13.7	12.3
						0.2		1.2	1.5	0.2	
					164-193	7.69	5	177.2	166.1	13.2	12.3
						0.12		2.5	2.4	0.4	
DDH — 15			1654	90	160-220	8.12	7	267.3	240.4	21.7	19.5
						0.15		1.5	0.9	0.5	
Best Value											19.5

[1] Number of conductivity samples.

[2] Harmonic average of conductivity measurements for DDH-4 and DDH-6

[3] Average of Helena "limestone" conductivities only.

clined drill holes are vertical depths from the surface above the point of temperature measurement. The quantity desired for the heat flow is the vertical geothermal gradient, but the procedure used to obtain vertical depth from lateral depth along the drill hole is successful only if the isotherms are horizontal. Experience shows that isotherms are seldom horizontal, even when they "ought" to be. Because detailed information is seldom available to properly take into account the dip of isothermal surfaces in inclined drill holes, such heat flow determinations are considered of lower precision than in vertical drill holes.

The mechanical details of data acquisition and reduction are summarized by Roy et al (1968b) and are listed in Table 1. The gradients are least-squares straight lines fitted to the temperature-depth data in the given interval. The conductivity values listed are mean harmonic averages. Standard errors are shown beneath the appropriate data entry. The errors shown for heat-flow values are statistical and relate only to the internal consistency of the data. The water table varies in depth in the drill holes from about 20 to 50 m. As there seems to be no systematic difference in gradients above or below water, gradients above and below the water table are not distinguished in Table 1. All heat-flow values, except those for DDH-12, 14, and 15 were calculated as the product of the least-squares gradient and average harmonic thermal conductivity. Heat-flow values in these three holes were calculated by the resistance-integral method.

Topographic corrections have been applied to all the drill holes for which heat-flow values were calculated. The correction was calculated in the conventional way (Birch, 1950), but was carried only to a distance of 2 km. The rapid lateral variation of the geothermal gradient and the possible recent nature of the heat flow anomaly make the assumptions necessary for calculating a terrain correction, tenuous at best. But certainly the close-in topography has an effect; hence the correction was arbitrarily carried to 2 km.

Ottawa Gulch

The lowest value of heat flow available in the Marysville area is in DDH-1 on Ottawa Gulch (see Figure 1). The hole cuts contact metamorphosed Empire Shale. The temperature-depth curve is shown in Figure 3. The terrain corrected value of heat flow is 3.2 μcal/cm^2 sec. The hole is isolated about 0.5 km north of the group of holes on Woodchopper Gulch and inclined into a hillside so the vertical gradient is rather poorly determined. DDH-2 is about 100 m along the hillside west of DDH-1, with the same inclination and bearing and thus furnishes redundant gradient data. The conductivity for DDH-2 is assumed to be the same as in DDH-1 because no samples were available from DDH-2.

Woodchopper Gulch

Five drill holes were measured in a relatively small cluster. The temperature-depth curves are shown in Figure 4. All the drill holes are in Helena Limestone which is less metamorphosed and impure than at the Bald Butte locality. All the drill holes are relatively shallow and all (excepting DDH-7) are inclined. The temperatures in the deepest hole (DDH-5) are disturbed by water entering the drill hole at the water table, about 50 m, and exiting at 113 m (vertical depths). The effect of the water circulation reaches all the way to the bottom of the drill hole, however, so only a lower limit for the gradient can be established. Drill holes 3 and 7 are extremely shallow and 3 is disturbed by water flow, so the heat-flow values are not included in the average.

The heat-flow values for the two drill holes (DDH-4 and DDH-6) which are thought to be the most reliable because of their depth, gradient linearity and sample availability, differ by about 10 percent. The holes are less than 200 m apart and have the same bearing and inclination so neither value is favored over the other. The best value for Woodchopper Gulch is the mean of DDH-4 and DDH-6: 4.7 μcal/cm^2 sec.

Continental Divide

Temperatures were measured in a single drill hole (DDH-8) on the Continental Divide between Woodchopper Gulch and Bald Butte. The hole is inclined at a rather shallow angle, thus the uncertainty in the vertical gradient is large. Because no thermal conductivity samples were collected, the average conductivity for DDH-4 and DDH-6 is used to calculate a heat-flow value. The uncertainty of the determination is quite high and the value is an estimate at best.

Bald Butte

Temperatures were measured in five drill holes. Heat-flow values, uncorrected for topography, have already been published (Blackwell, 1969, p. 995, and Figure 5) for three of the drill holes (DDH-9, 11, 12). Temperatures were also measured in DDH-10 and DDH-13 (Figure 5). DDH-10 is very shallow and a heat-flow value is not calculated; however, the heat flow in DDH-13

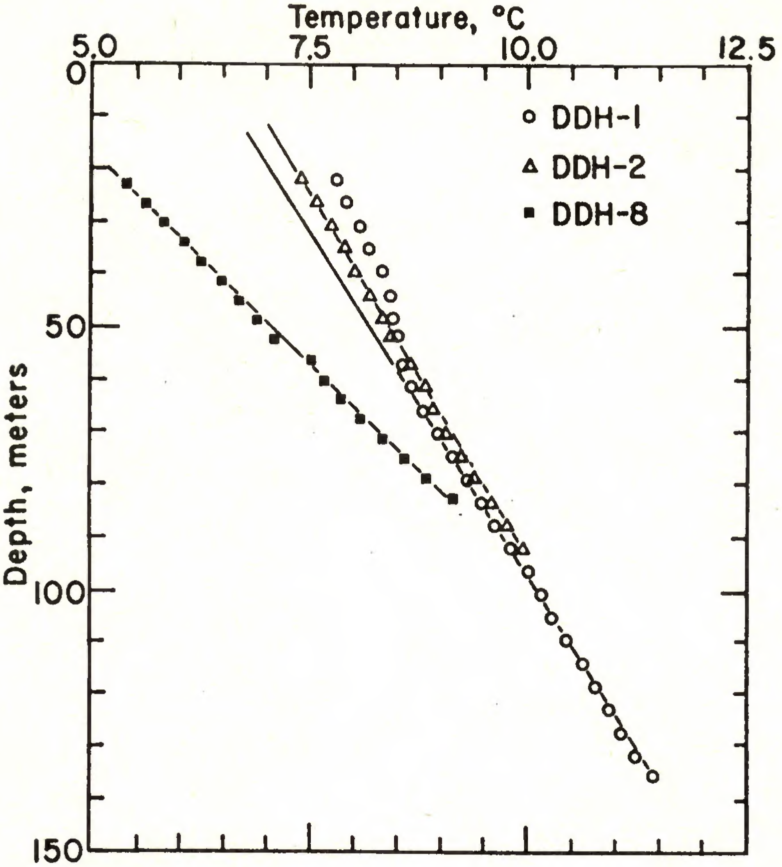

FIG. 3. Temperature-depth curves for the Ottawa Gulch (DDH-1, and DDH-2) and Continental Divide (DDH-8) localities.

is calculated and included in the average. Two series of temperature-depth measurements are plotted for DDH-13. During the first logging, a small water flow was issuing from the collar. Before the second logging, the water flow had stopped. The logs clearly indicate the entry of water into the drill hole at 130 m. The drill holes cut hornfelsed Helena Limestone, which in this locality was quite silty and has been transformed into a dark rock composed of calc-silicate minerals cut by numerous quartz veins.

DDH-9 cuts the small porphyry stock intruding the Helena (Rostad, 1969) and has a similar gradient to the remainder of the drill holes, but a higher conductivity and thus a higher heat flow. This heat flow has not been included in the average as it is assumed to be a refractive effect. The shape of the stock is similar to a needle and so the heat flow around the stock will not be affected measurably by its presence. Thus, the true regional heat flow in DDH-9 is given by the Helena conductivity and the observed gradient.

The terrain-corrected heat-flow values have a greater scatter than the uncorrected data. However, the terrain-corrected gradients, unlike the uncorrected gradients, do not differ at a 1 σ confidence limit and heat-flow differences are due to conductivity alone. Therefore, the best value of heat flow for the locality is taken as the harmonic mean of all the Helena Limestone conductivities in DDH-11, 12, and 13, and the arithmetic mean of the geothermal gradients in DDH-9, 11, 12, and 13. The best value of heat flow corrected for nearby topography is 6.5 μcal/cm^2 sec.

Heat Flow

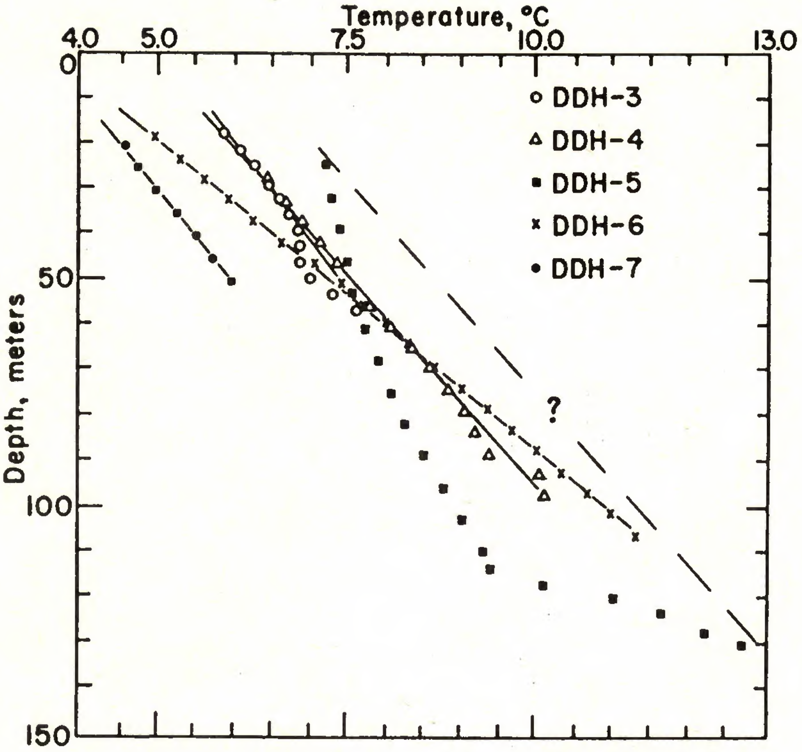

FIG. 4. Temperature-depth curves for the Woodchopper Gulch locality (DDH-3, 4, 5, 6, and 7).

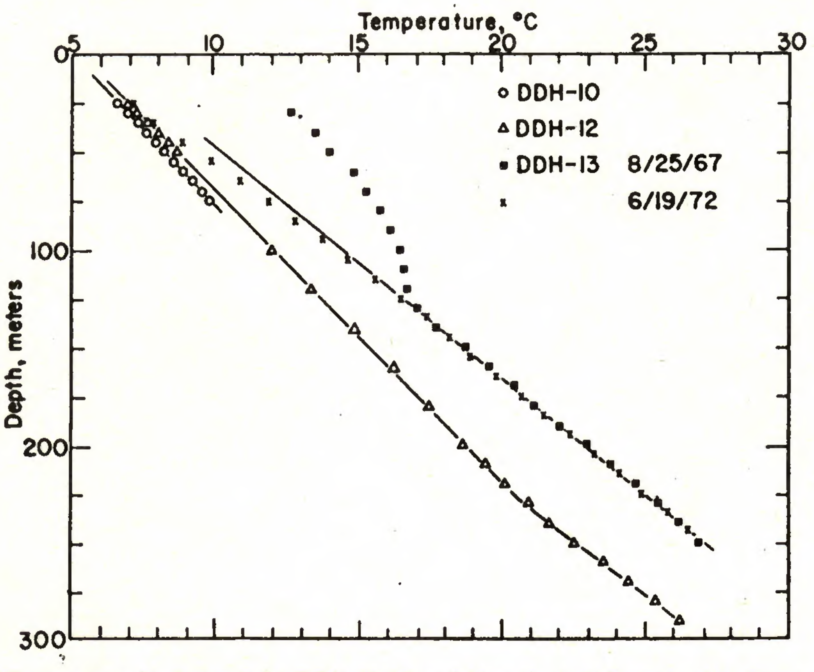

FIG. 5. Temperature-depth curves for DDH-10, 12, and 13 at the Bald Butte locality. Temperature-depth curves for DDH-9, 11, and 12 are shown in Blackwell (1969, Figure 5).

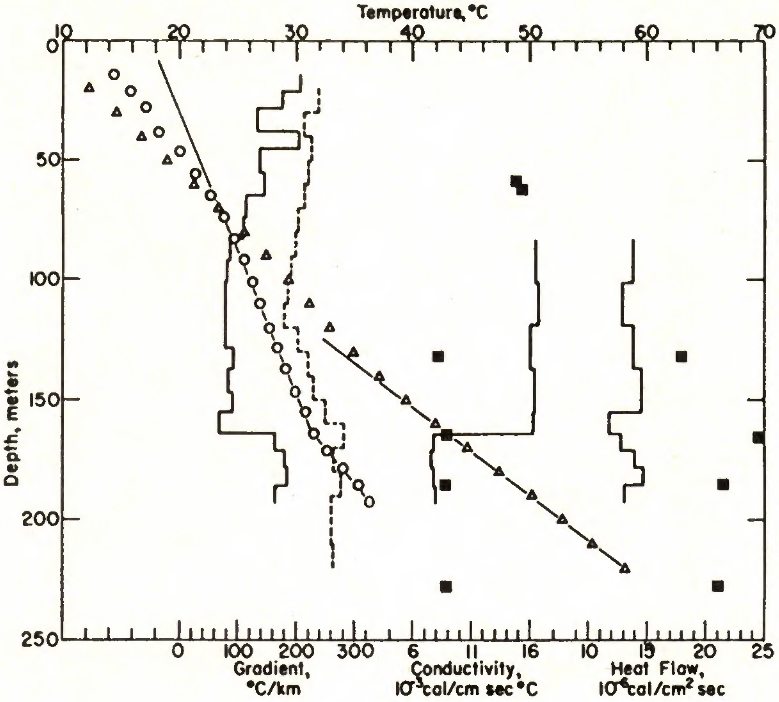

FIG. 6. Temperature-depth curves for DDH-14 (circles) and DDH-15 (triangles) at the Empire Creek locality. Bar graphs of gradient, thermal conductivity, and heat flow are shown for DDH-14. A bar graph of gradient for DDH-15 (dashed curve) is also included. The solid squares represent depths of thermal conductivity measurement and spot heat flow values for DDH-15. Not all available conductivity measurements for the hole are shown, however, as some are below the interval plotted.

Empire Gulch

The two drill holes (DDH-14 and DDH-15) cut a small quartz porphyry stock below a quartz cap. The two units are clearly shown in the bar graphs of gradient and thermal conductivity (Figure 6). The lower part of the quartz cap is horizontal because, although the thermal conductivity is twice as high in the quartz cap as in the porphyry (determined as the harmonic mean of the samples from DDH-14 and DDH-15), the heat flow is exactly the same (Table 1)! The rock cut by the intrusive is Empire Shale dipping less than 30 degrees. Similar rocks (Belt Series argillites) elsewhere for which data are available have conductivities in the range of 7-8 mcal/cm sec °C (Blackwell, 1969, unpublished), as does the Empire Shale in DDH-1 in Ottawa Gulch. Thus, thermal conductivity of the quartz porphyry and shale are similar and the heat flow, although measured in the porphyry, cannot have a significant refraction component.

Possible errors introduced by calculating vertical gradients from inclined drill holes are clear at this locality. The isothermal surfaces are dipping in the direction of the inclination of DDH-14 so the calculated "vertical" gradient differs from the true vertical gradient by 35 percent. The inclination of the isothermal surfaces is into a hillside, contrary to the expected behavior. Thus, the best value of heat flow is the one measured in the vertical drill hole (DDH-15). That value is 19.5 μcal/cm² sec.

ORIGIN OF ANOMALOUS HEAT-FLOW VALUES

A summary of heat flow, gradient, and conductivity information for each of the five localities is shown in Table 2. The regional heat flow in western Montana is "high" and is about 1.9 μcal/cm² sec (Blackwell, 1969 and unpublished data); thus the lowest value of heat flow measured in the Marysville area is almost twice the background. The "anomalous" gradient at each locality (which is the number to be used in the interpretation section) is obtained by subtracting

Table 2. Heat flow, thermal conductivity, gradient, and anomalous gradient

Locality	No. of Holes	Heat Flow μcal/cm^{2}sec	K μcal/cmsec°C	Gradient °C/km	Anomalous Gradient °C/km ($\pm$percent)
Ottawa Gulch	2	3.2	7.50	42.7	17.4 ± 25
Woodchopper Gulch	2	4.7	7.06	66.6	39.7 ± 5
Continental Divide	1	(5.0)	(7.06)	70.5	43.6 ± 25
Bald Butte	4	6.5	8.08	80.2	56.7 ± 5
Empire Creek	1	19.5	8.12	240.4	217.0 ± 5

the gradient corresponding to a background heat flow of 1.9 μcal/cm^2 sec and the in-situ thermal conductivity, from the observed gradient. The results are shown in Table 2. The error band which should be associated with the "anomalous" gradient is difficult to estimate. A figure of ± 5 percent is probably reasonable for the Empire Creek, Bald Butte, and Woodchopper Gulch localities. For the Ottawa Gulch and Continental Divide localities the band might be as large as ± 25 percent. Hence, in subsequent sections, the models are constrained primarily by the Empire Creek, Bald Butte, and Woodchopper Gulch data.

The observed heat-flow pattern, with the exception of the Ottawa Gulch locality, is compatible with sources of simple shape. If the heat flow at the Ottawa Gulch locality is valid, then the source cannot have a simple shape because Ottawa Gulch is closer to Empire Creek than is Woodchopper Gulch. However, because of the lack of data available to fully define a source shape and because the heat-flow value at Ottawa Gulch is not well determined, the value there will be neglected in the following sections. Nonetheless, the value in Ottawa Gulch may indicate a complicated source shape.

For purposes of the discussion, some limits need to be put on the minimum depth to the source of the anomaly. Information on the maximum depth comes from the succeeding analysis. DDH-15 was drilled to a depth of almost 550 m and remained in quartz porphyry to the total depth. The hole was supposed to have been cased with iron pipe to 440 m, but for unknown reasons the temperature probes will not go below 220 m. Extrapolation of the observed gradient implies a bottom-hole temperature of 140-150°C. Had a water reservoir at such temperatures been penetrated, there would have been no doubt about it. This evidence, plus the fact that local relief over the anomaly exceeds 500 m, suggests that the minimum depth to the top of the source must be in excess of 550 m in Empire Creek.

Because of the size and strength of the anomaly, explanations such as refraction, radioactive sources, or oxidization of sulfides can be ruled out. The only reasonable explanations are a buried reservoir of thermal fluid or a buried, still cooling magma chamber! On the basis of presently available data, either hypothesis could explain the data so both will be discussed.

Hot water reservoir

In other areas where high values of conducted heat flow similar to the value in Empire Creek have been measured, their origin has been attributed or proved to be convection at depth of heated groundwater (see for example, Helgeson, 1968; White et al, 1971). In fact, Rikitake (1959) developed a model (to be used in the following section) for a spherical magma chamber, in order to explain a heat-flow value of 12 μcal/cm^2 sec. However, from the results of the model he concluded that the chamber would have to be at an unreasonably shallow depth (in his case) for heat-flow value to be explained by such a model. Thus, he concluded that the value was due to convecting groundwater.

In the Marysville area there is no obvious reservoir in the area where high values are observed, and there are no surface manifestations of high-temperature fluid at depth (such as hot or warm springs or recent volcanics). In fact, there are few large springs at all in the district. The country rocks (Precambrian sediments of the Belt Series) are extremely impermeable except for permeability due to interconnected fractures. The anomalous heat-flow values are separated by a distance of over 5 km and do not appear to have any systematic structural relationships with mapped geology or faults. In order to explain the spread of heat-flow data, any reservoir must have a lateral extent of several kilometers, but no obvious possibilities appear in the geology; lack of thermal springs argues against the presence of a high degree of fracture porosity in the rocks of the area.

In the rank of pure speculation, it might be possible that regional low-angle thrust faults of large displacement, mapped to the east, extend beneath the Marysville district and that a suitable reservoir might be fractured rock along, or permeable Paleozoic carbonates below, the thrust fault. The zone of thrust faulting is continuous with that to the north (Robinson et al, 1968) which includes the Lewis Overthrust of the Glacier Park area and the McConnell Overthrust in Canada. Demonstrated net slips of 45 km or more are available for these faults (see Fox, 1959). The nearest mapped, large displacement thrust fault to the Marysville district is the Eldorado thrust fault just west of Wolf Creek, Montana (Schmidt, 1963) approximately 40 km to the northeast. The Eldorado thrust has a stratigraphic throw of several kilometers, but the net slip is unknown.

Assuming a suitable reservoir is present, little can be said about its temperature, size, and depth because of lack of data. If the observed gradients in Empire Creek extend only 500 m below the maximum depth of DDH-15 and the reservoir is present at that depth, the temperature would be on the order of 250°C, or about as high as observed in other presently known geothermal areas. If the reservoir is beneath a regional thrust fault, then measurements presented here would reflect conducted heat flow in the impermeable cap over the reservoir and indicate the pattern of convection in the reservoir.

Buried magma chamber

In view of the lack of evidence for a hot water reservoir, other possibilities ought to be considered. Recent studies of geothermal systems suggest that the source of heat for such systems must be magma chambers at depths of several kilometers (Bodvarsson, 1970, for example). Therefore, it seems reasonable that other magma chambers may be present whose heat is not tapped by groundwater because of lack of water or impermeability of wall rocks. The Marysville anomaly may represent one such area.

Three very simple models will be discussed: infinite, semiinfinite, and spherical *instantaneous* (Carslaw and Jaeger, 1959, p. 255) heat sources. The semiinfinite model represents the maximum (and undoubtedly unrealistic) size for the causative body while the spherical model represents much smaller body size. The models assume uniform thermal properties for magma and wall rocks, a temperature of intrusion of 1000 or 1300°C, simple conductive cooling and a *single* pulse of magma intrusion. The ground surface temperature (a planar surface is assumed in the calculation) is kept constant for all time by use of the method of images. Details of the solidification of a magma chamber (such as a convection in a cooling magma) are ignored, as is detailed consideration of the effect of the latent heat of solidification. Jaeger (1965) notes that for instantaneous models the initial temperature used can account approximately for effects of latent heat if, instead of melting temperature T_m, the initial temperature used is $T_0=T_m+L/c$, where L is the latent heat and c is the specific heat of the magma. So for a latent heat of 50 cal/gm, and a specific heat of 0.2 cal/gm°C, $T_0=T_m+250°C$. Thus, the assumed initial temperatures correspond roughly to melting temperatures of granites and gabbros. Such simple models are justified only by the lack of information on possible composition of the magma (and thus the initial temperature), physics of solidification in a magma chamber, and lack of detailed surface data to limit possible model shapes or histories.

An interesting relationship can be derived for the maximum gradient at the surface of a plane layer, initially at $T=0°C$ everywhere, overlying a half-space with an initial temperature of T_0 (temperature at time = 0), followed by subsequent simple conductive cooling with the upper surface of the plane layer remaining at $T=0°C$. It is merely

$$(dT/dz)_{z=0} = 0.48(T_0/H), \qquad (1)$$

where $(dT/dz)_{z=0}$ is the surface gradient, and H is the thickness of the capping layer. Thus, the maximum gradient at the surface is independent of the thermal properties and is never more than approximately one-half the initial temperature divided by the depth to the top of the chamber. The timing of the appearance of the maximum gradient at the surface (and the variation with time of the gradient) is a function of the diffusivity of the material. The times at which models with various capping layer thicknesses and initial temperatures would satisfy the observed gradient at the Empire Creek locality are shown in Figure 7. The diffusivity assumed is 0.015 cm^2/sec. For the one-dimensional instantaneous model, the maximum possible depth to the top of the chamber is only 2.4 km if T_0 is 1000°C, and less than 3.0 km if $T_0 = 1300°C$ (Figure 7). The magnitude of the anomalous gradient at the Empire Creek locality represents a severe constraint on the depth to the source of the anomaly. The age of the intrusion could range from a few thousand to 150,000 years based on this model.

The maximum depth to the corresponding chamber, if it has existed long enough to reach steady state, is just over twice the depth for the instantaneous model with the same T_0 because the gradient in the steady-state case will be

$$(dT/dz)_{z=0} = (T_0/H), \tag{2}$$

where the symbols are the same as in equation (1).

The data from Woodchopper Gulch and Bald Butte indicates that one boundary of the body must be between those two localities and the Empire Creek site, however. A model which maximizes the size of the body is one which assumes the body to be infinite in extent to the north, south, and west and to have a boundary striking northwest-southeast or north-south between Empire Creek and Bald Butte. For simplicity the body will be assumed to have a vertical plane boundary between Empire Creek and Bald Butte. The geometry of the model for which calculations are made is shown in Figure 8. Also shown in Figure 8 are the gradients from the three localities with highest-quality data projected onto northwest-southeast and north-south cross-sections. For a few classes of instantaneous models, i.e., those that can be made up of a product of one-dimensional solutions, the shape of the surface gradient curve uniquely gives the time of intrusion as well as information which can be used to put limits on the depth to the top of the body and its thickness. The geometry shown in Figure 8 has been analyzed by Simmons (1967). For the class of models shown, the surface gradient is given by

$$(dT/dz)_{z=0} = \frac{T_0}{2\sqrt{\pi k t}} \left(e^{-z_2^2/4kt} - e^{-z_1^2/4kt}\right) \cdot \left\{1 + \operatorname{erf}\left[x/(4kt)^{1/2}\right]\right\}, \tag{3}$$

where z_2 and z_1 are the depths to the bottom and top of the body, respectively, and k is thermal diffusivity. If x_0 is the distance from the midpoint of the anomaly ($x = 0$ in Figure 8) required for the anomaly to drop to 52 percent of the midpoint value, then the time since intrusion is

$$t_0 = x_0^2/k. \tag{4}$$

With $t = t_0$, equation (3) for the maximum amplitude at any time becomes

$$G_m = (dT/dz)_{max} = \frac{T_0}{x_0\sqrt{\pi}} \left(e^{-z_2^2/4x_0^2} - e^{-z_1^2/4x_0^2}\right). \tag{5}$$

So from the anomaly shape and magnitude, a unique time (assuming the shape is exactly known and the assumed model is identical to the causative body) and an infinite set of (z_1, z_2) can be found which will satisfy the anomaly. The am-

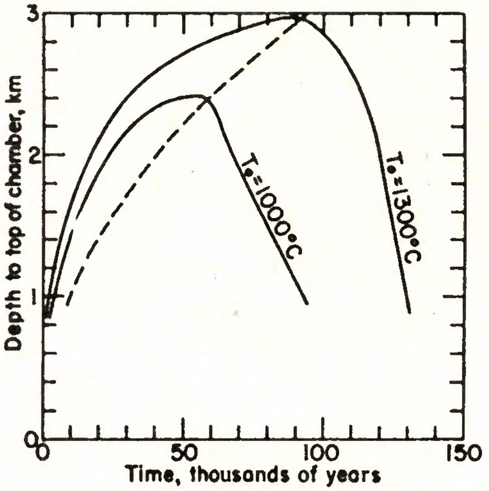

FIG. 7. Plot showing locus of time when an infinite instantaneous (see text) magma chamber with a roof of thickness given by the ordinate value and with the specified initial temperature would have a surface gradient of 220°C/km. The dotted line is the locus of the time of maximum gradient for a given roof thickness.

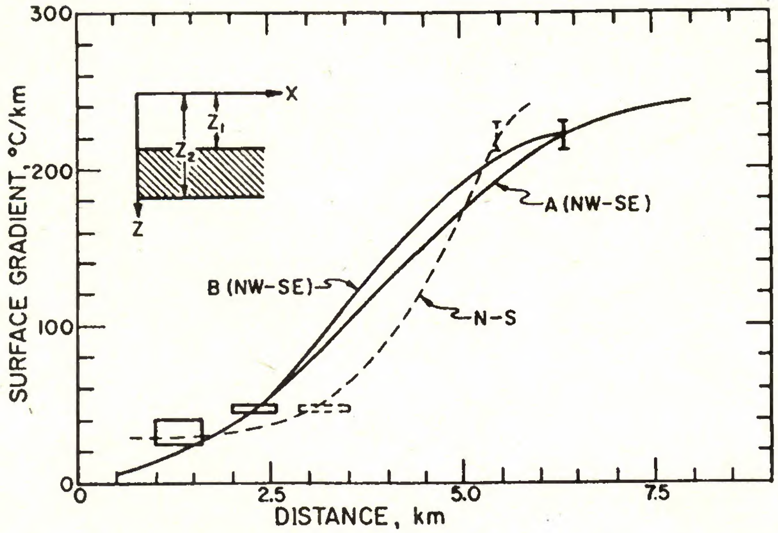

FIG. 8. Anomalous gradient data from Empire Creek, Bald Butte, and Woodchopper Gulch projected onto north-south (dashed) and northwest-southeast (solid) cross-sections. The size of the symbol is proportional to the uncertainty of measurement. The interpretational model is shown in the left corner. Models A and B are discussed in the text (see also Figure 9).

biguity is illustrated in Figure 9 which is a contour plot of $T_0/G_m x_0$ as a function of scaled depth to the top of the body (z_1/x_0) and scaled body thickness $[(z_1-z_2)/x]$. As the figure illustrates, for a given anomaly and values for x_0, G_m, and T_0, there are many pairs of z_1 and z_2 which will satisfy the observations.

In order to apply the model, the data shown in Figure 8 were used to define an anomaly curve. The shape of the anomaly implied by the north-south projection (dashed line) is not similar to those generated by the model considered here because of the tail of the anomaly, whereas the data projected onto the northwest-southeast profile are consistent with such a model. Two interpretations of the possible anomaly shape are shown in Figure 8 (indicated by A and B). Curve A has values of x_0, t_0, and G_m equal to 1.1 ± 0.1 km, 25,200 ± 7000 years, and 225°C/km, respectively, while curve B has values of 1.35 ± 0.15 km, 38,000 ± 10,000 years and 250°C/km. The range of values of the quantity $T_0/G_m x_0$ are shown in Figure 9 for those two models assuming values of T_0 to be between 1000 and 1300°C. Values of the parameter z_1/x_0 less than 0.6 can be ruled out by the drill hole in Empire Creek. Models with z_1/x_0 greater than 1.5-2.0 (the exact value depends on the value of $T_0/G_m x_0$) where the contours become horizontal, are insensitive to the thickness of the body.

For this model to be applicable, the extent of the body does not have to be infinite to the northwest, northeast, and southwest. If the plan section

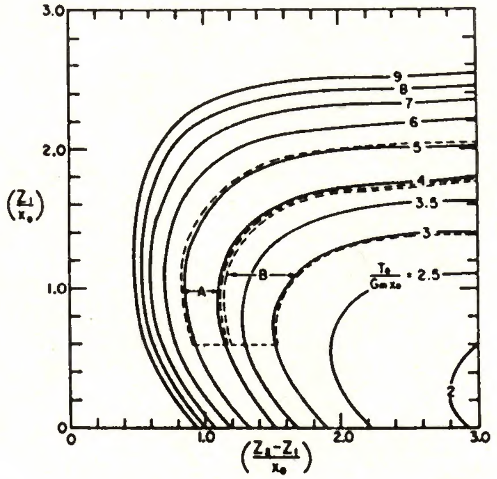

FIG. 9. Contour plot of the dimensionless parameter $T_0/G_m x_0$ as a function of scaled depth to top of the body (z_1/x_0) and thickness of the body $[(z_2-z_1)/x_0]$ for the model shown in Figure 8. The dashed curves correspond to the range of parameters which would generate anomaly curves A and B in Figure 8, assuming T_0's of 1000°C and 1300°C.

of the body is a square or rectangle with sides greater than 6–10 km, then the model used here would still be valid. Therefore, more data are obviously needed to the northwest and southwest to furnish constraints upon this sort of model.

A final model to be considered, and the one that probably comes closest to being a physically reasonable model, is a spherical source. As before, the calculation is for instantaneous intrusion and subsequent conductive cooling. The equations describing the surface gradient and the internal temperature of such a source have been derived by Rikitake (1959). The initial temperature is assumed to be 1300°C and the diffusivity and other assumed quantities are as before. With this model, and the above conditions, no single source with center to the northwest of the Empire Creek determination will satisfy the observed gradient data; if the source is spherical, the axis of the sphere must lie between Bald Butte and Empire Creek. The results of the calculations, and the models, for three cases that satisfy the gradient data, are shown in Figure 10. In cases 1 and 3 the chambers are 3 km in diameter, buried 1 km beneath the surface, and have ages of 40,000 and 60,000 years, respectively. In case 2, the chamber is 4 km in radius, buried 1.5 km and has an age of 40,000 years. The surface projections of the centers of these chambers are shown as circled numbers in Figure 1. Figure 11 shows calculated temperatures in the chamber for the three spherical models. It must be reemphasized that the initial assumptions and model upon which these examples are based are tenuous at best and give only order of magnitude estimates of possible subsurface conditions.

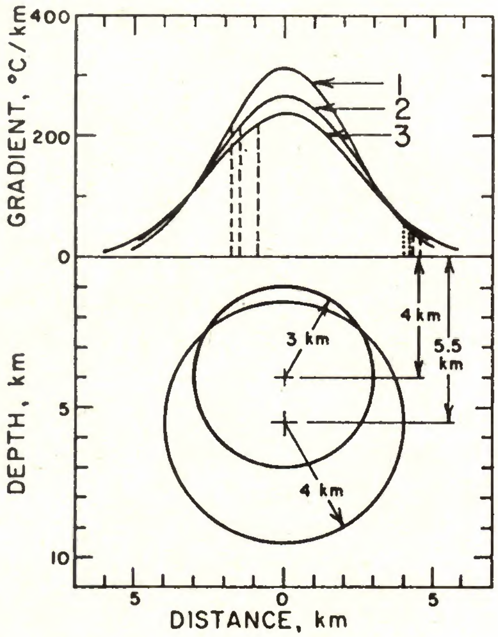

FIG. 10. Spherical magma chambers, calculated surface gradients, and observed data (dotted and dashed lines). Assumed diffusivity is 0.015 cm²/sec. Model 1 has a magma chamber 3 km in radius, center buried 4.0 km, and 40,000 years old. Model 3 is the same as Model 1, but with an age of 60,000 years. Model 2 has a magma chamber 4 km in radius; center buried 5.5 km and age of 40,000 years.

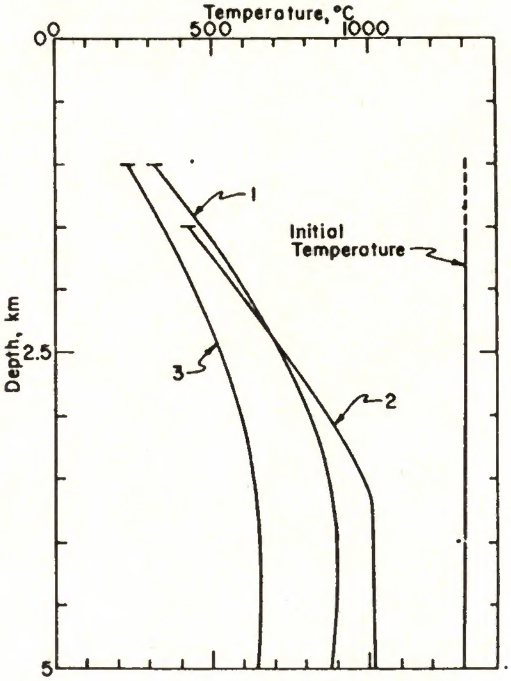

FIG. 11. Current and initial temperatures in the magma chamber for the three spherical models (Figure 10).

HEAT-FLOW DETERMINATIONS IN SHALLOW BOREHOLES

Theoretically, it should be possible to make heat-flow measurements with only a single logging in boreholes deeper than 20 m, the depth at which the temperature variation due to the seasonal air temperature variation becomes negligible for typical values of thermal properties (see Lovering and Goode, 1963, for a detailed discussion). In practice, heat-flow measurements may not be considered reliable unless the holes are 200–300 m deep (see Birch, 1966). The gradients measured in the shallow parts of drill holes (even in regions of gentle topography) often depart remarkably from those measured deeper in the drill holes, particularly in regions of low to normal heat flow. These "anomalous" shallow gradients have been attributed to conductive effects such as recent climatic changes or to nonconductive effects such as "water circulation" (Diment, 1964; detailed discussion by Birch, 1966). Water circulation between fracture zones or aquifers cut by a drill hole is readily identifiable by the stair step nature of the temperature depth curves (Birch 1966, Figure 8; DDH-5 at Woodchopper Gulch, etc.). It is now clear that most other effects not directly attributable to obvious water circulation in the drill hole are related to steady state or transient variations in ground surface temperature due to vegetation contrasts (Hyndman and Everett, 1968; Roy et al, 1972). In the conterminous U.S., at least, general climatic effects do not seem to be present. Vegetation contrasts can cause ground surface temperature variations of up to 2°C over a lateral distance of a few tens of meters (see Poley and Van Stevenick, 1970). The resulting effect on geothermal gradients can be as much as ±20°C/km at shallow depths, but the most drastic cases can be easily recognized (as when the hole is drilled in a small clearing, for example) and a correction applied. Furthermore, in geothermal areas the enhancement of heat flow (and thus of gradient) may be 2–10 times normal, and thus the gradient error from such effects will be much less than in the eastern U.S., for example.

Measurements were made in most of the drill holes at Marysville beginning at 10 m. Comparisons of the uncorrected interval average gradient between approximately 20 and 40 m and the uncorrected least-squares gradient in the segment of the drill hole used for the heat-flow calculation (Table 1) are shown in Table 3 for the drill holes for which data are available. The results are encouraging for the possibilities of making gradient measurements in shallow holes. The difference between the two gradients for each drill hole (column 5) includes the effects of possible conductivity variations (in general, no thermal conductivity samples were collected from as shallow as 40 m), water table effects (the water tables in the holes range from a few meters to 50 m or so), different depth weight of topographic effects, and errors of calculation as well. Clearly it should be possible to make heat flow measurements in shallow holes when gradients are high and rocks are impermeable.

Even where gradients are high, vegetation contrast effects can still be significant. Some of the scatter of uncorrected gradients at the Woodchopper Gulch locality is due to such effects. These contrasts are indicated by the difference in extrapolated surface temperatures between the

Table 3. Comparison between uncorrected shallow gradients (between approximately 20 and 40 m) and the uncorrected least-squares gradients used to calculate heat flow values (Table 1)

DDH No.	Shallow Gradient °C/km	Depth Interval[1] meters	Uncorrected Gradient °C/km	Difference Percent
1	30.6	70-135	37.1	−17.5
2	35.8	31-92	35.3	+1.4
3	48.9	18-64	46.0	+6.3
4	49.4	29-97	52.4	−6.7
6	70.9	28-106	72.2	−1.8
7	45.5	30-50	49.4	−7.9
8	57.2	30-82	63.0	−9.2
10	64.5	60-80	65.5	−1.5
11	85.0	52-281	72.5	+17.2
12	67.5	100-280	70.3	−4.0
13	76.5	140-250	83.9	−8.8
14	180.3	164-193	177.2	+1.7
15	231.5	160-220	267.3	−13.4

[1] Values apply to the uncorrected least-squares gradients.

pairs of holes DDH-6 and DDH-7 (3.5°C, in trees) and DDH-3 and DDH-4 (5.0°C, in a clearing) even though the drill holes are less than one hundred meters apart. The gradients corrected for the vegetation contrasts and topography differ by much less than the raw data.

Thus it seems that, given appropriate conditions not as restrictive as previously assumed, geothermal gradients can be measured in shallow drill holes which will be in reasonable agreement with those measured at greater depths. The conditions are that the hole not be in an area of high relief, that no obvious shallow aquifers with moving groundwater be present, and that variations in surface temperature due to vegetation contrasts or other effects (lakes, recent logging, cities, etc.) are not present. To a certain extent the gradient anomalies caused by surface temperature variations can be removed. Certainly, the chances for making a successful gradient measurement are improved if the gradient is higher than normal and if more than one hole in a given area is available. These conclusions are supported by data from a study of the geothermal gradient and heat flow in southeastern Oregon where elevation, vegetation, and aquifer effects are in general not present (see Bowen and Blackwell, 1973). The rocks are mostly relatively unconsolidated lake bed deposits, tuffs, and volcanics with low thermal conductivities so that the gradient, even for a background heat flow of about 1.5 μcal/cm^2 sec, is 40–50°C/km. In those holes, almost without exception, the geothermal gradient is sensibly constant from approximately 20 m to (in the absence of conductivity variations) the total depth of the drill hole.

DISCUSSION

The unique feature of the Marysville anomaly is that there are no surface manifestations of anomalous subsurface temperatures in spite of a heat flow 10 times the regional average. Such an area of high heat flow is of interest both from its contribution to the understanding of the thermal structure of the crust and from its possible use as a source of thermal energy.

Many other "blind" geothermal areas such as the one described here undoubtedly exist in the western U.S. Regional heat flow studies in that area have delineated three broad regions of high heat flow (Roy et al, 1968b, 1972; Sass et al, 1971). The average regional heat flow in these zones of high heat flow is about 2.2 μcal/cm^2 sec. In the areas of high regional heat flow, except in extremely unusual situations, heat flow values in excess of 3 μcal/cm^2 sec cannot be explained unless some extra component of heat flow is present, in addition to the mantle component and the component due to radioactive decay in the crust (see Roy et al, 1968a). Yet of the approximately 200 measurements (if anything, biased against sites near geothermal areas as most are in holes drilled for mineral exploration) so far published in the high heat-flow zones (Roy et al, 1968b; Warren et al, 1969; Sass et al, 1971; etc.), approximately 10 percent of the measurements have values in excess of 3 μcal/cm^2 sec. Thus, there are many other areas similar to Marysville in the western U.S. However, most of the other areas of extra high heat flow are represented by a single measurement, whereas at Marysville there are enough closely spaced measurements to give some idea of the size and intensity of the anomaly.

Additional geophysical studies are in progress in the Marysville area in order to delineate further the geographic limits of the anomaly and identify the nature of the source. These studies include further drilling and a gravity survey. Seismic surveys are also planned. Electrical studies of the area are in progress by the USGS. The models presented above are only considered for order of magnitude ideas as to the implications of the heat flow data. Further studies should give much more definitive information on the source size, shape, and intensity.

At present it is not clear that the area would have been recognized by other geophysical investigation. Thus, in high heat flow regions of the western U.S., regional heat-flow studies alone may discover many of these "blind" anomalies. Such surveys might be sponsored by state or federal agencies in order to delineate anomalous areas for further study by government or industry. If drill holes 30 m (100 ft) deep can be utilized, then many previously drilled shallow holes should be available that have been ignored in previous regional surveys. The desirable spacing of these types of measurements would be less than 5 km.

ACKNOWLEDGMENTS

William R. Wade and AMAX Exploration, Inc. made available drill holes, core samples, and geologic information essential to the study. Ora H. Rostad, Giles Walker, and Eugene C. Robertson provided assistance, information, and discussion during the course of the study. M. Ratcliffe provided unpublished geologic information on the Marysville district. Dr. Francis Birch pointed out the relationship of the surface heat flow to the capping thickness for the semiinfinite instantaneous model discussed in the text. The field and laboratory measurements were made by R. Spafford and R. A. Arnett. The work was supported by National Science Foundation Grant GA 11351 to Southern Methodist University.

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APPENDIX B

EXISTING COOPERATIVE RESEARCH CONTRACT

MISSOULA D.O. COPY

BNW CONTRACT NO. B-790

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT

COOPERATIVE RESEARCH CONTRACT

THIS CONTRACT is made and entered into under authority of the Public Lands Administration Act (P.L. 86-649; 74 Stat. 506; 43 U.S.C. 1361-1363) between the UNITED STATES OF AMERICA, hereinafter called the Government, acting by and through the Bureau of Land Management, and Battelle PACIFIC NORTHWEST LABORATORIES, hereinafter called the Contractor.

WITNESSETH, That the parties hereto do mutually agree as follows:

Sec. 1. Purpose: This contract is for the purpose of investigating and evaluating the occurrence, extent, and properties of geothermal resources in the contract area, and possible recovery and conversion of energy therefrom.

Sec. 2. Contract Area: The contract area is all the National Resource Lands within the following described area:

Principal Meridian, Montana

T. 11 N., R. 5 W., Sec. 4, 5, 6, 8.

T. 11 N., R. 6 W., Sec. 1, 2, 3, 4, 10, 11.

T. 12 N., R. 5 W., Sec. 5, 19, 20, 29, 30, 31, 32, 33.

T. 12 N., R. 6 W., Sec. 5, 6, 7, 18, 19, 20, 21, 22, 25, 26, 27, 28, 29, 30, 32, 33, 34, 35, 36.

T. 12 N., R. 7 W., Sec. 1, 12, 13, 23, 24, 25.

Sec. 3. Rights Granted: This contract is entered into subject to any and all valid existing rights. The Government hereby authorizes the use of the contract area for the purposes stated in Sec. 1, for (1) casual surface occupancy such as motor vehicle travel on existing roads and trails, installation of instrumentation packages with hand tools, and other nondisruptive activities; (2) drilling of 2,000 feet of small diameter (maximum 5 inches diameter) core holes, subject to prior written approval by the authorized officer of any and all drill hole sites. The Contractor's rights shall be subject to the right of the Government to issue leases, permits, or licenses in the contract area under the Geothermal Steam Act of 1970 (30 U.S.C. 1001-1005) or under any other statute.

Sec. 4. Period and Terms: The period of this contract shall be from date of approval by the State Director until July 31, 1974. This period coincides with the grant period of National Science Foundation Grant Number GI 38972. This contract may be extended, terminated, canceled, suspended, or modified at the discretion of the contracting officer.

Sec. 5. Assignments, Subcontractors: This contract may not be assigned. The Contractor shall designate an official by name to whom all matters relating to this contract shall be addressed, and shall provide a list of names and addresses of all subcontractors and their representatives who will be performing activities under this contract. This list shall at all times be kept current by the Contractor. Any and all subcontractors shall be bound by all terms and conditions of this contract.

Sec. 6. Availability of Data: All data obtained and conclusions or estimates based thereon shall be shared with the Government at no cost. The Contractor shall submit to the Government not later than six months after the termination of this contract a report analyzing the data.

Sec. 7. Limitation of Rights: Neither the Contractor, nor any subcontractor, nor any other participant(s) in this contract or operations thereunder, shall acquire any right to a lease, permit, or claim, nor to preferential treatment nor shall equities be deemed to accrue as a result of any data or information obtained under this contract. The Contractor and subcontractors stipulate by execution of this contract that data acquired from or based on the authorized research activities shall not be relied upon to support an application for patent, permit, or lease nor submitted as evidence in any administrative or court proceeding to which the Government is a party.

Sec. 8. Bond: A performance bond shall be filed by Contractor on or before the date this contract is signed by the authorized officer in the amount of $5,000 to cover damages that may be caused to the environment or resources within or outside the contract area.

Sec. 9. Equal Opportunity Clause: The attached equal opportunity clause, Form 1140-2, is made a part of this contract.

Sec. 10. General Surface Protection Provisions: The Contractor will be required, among other things, to: (1) conduct its activities in such a manner as not to interfere with or endanger other land uses; (2) conduct its activities in such a manner as to preserve and protect the environment including land, water, and air, to restore any damages to such environment, and to conserve all other natural resources; (3) to comply with all applicable Federal, State, and local regulations and requirements; and (4) to conduct its activities in accordance with the following terms and conditions:

(a) All operations shall be conducted in such a manner to avoid (a-1) blockage of any drainage systems; (a-2) changing the character, or causing the pollution or siltation of rivers, streams, lakes, ponds, waterholes, seeps, and marshes; and (a-3) damaging fish and wildlife resources or habitat. Cuts or fills causing any of the above-mentioned problems will be repaired immediately in accordance with specifications of the authorized officer.

(b) Trails and campsites shall be kept clean. All garbage and foreign debris shall be eliminated as required by the authorized officer.

(c) The Contractor shall protect all survey monuments, witness corners, reference monuments, and bearing trees against destruction, obliteration, or damage. He shall, at his expense reestablish damaged, destroyed, or obliterated monuments and corners, using a licensed surveyor, in accordance with Federal survey procedures. A record of the reestablishment shall be submitted to the authorized officer.

(d) The Contractor shall make every reasonable effort to prevent, control, or suppress any fires started by the operator, and to report, as soon as possible, to the authorized officer location and size of fires, and assistance needed to suppress such fires. The Contractor shall inform the authorized officer as soon as possible of all fires, regardless of location, noted, or suppressed by independent action. The Government reserves the right to close any area to operators in periods when fire danger or other dangers to natural resources are severe.

(e) Safety and Health - Contractor shall conduct all operations in connection with this contract in compliance with the applicable provisions of Federal, State, and local safety, health, and sanitation laws, codes, and regulations, and shall make it possible for the authorized officer to inspect such operations.

R F Kenner
Battelle Northwest Institute

7/23/73
Date

David D Blackwell
Southern Methodist University

7/25/73
Date

H. Rogers Jr.
President
Rogers Engineering Co., Inc.

H. ROGERS, JR.
PRESIDENT

7/20/73
Date

AUTHORIZED OFFICER:

John F Fields
District Manager, Missoula
Bureau of Land Management

7/27/73
Date

APPROVED - CONTRACTING OFFICER:

Edwin Zaidlicz
State Director, Montana
Bureau of Land Management

8/17/73
Date

Form 1140-[illegible]
(September 1969)

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT

EQUAL OPPORTUNITY CLAUSE

During the performance of this contract, the contractor agrees as follows:

(1) The contractor will not discriminate against any employee or applicant for employment because of race, color, religion, sex or national origin. The contractor will take affirmative action to ensure that applicants are employed, and that employees are treated during employment, without regard to their race, color, religion, sex or national origin. Such action shall include, but not be limited to the following: employment, upgrading, demotion, or transfer; recruitment or recruitment advertising; layoff or termination; rates of pay or other forms of compensation; and selection for training, including apprenticeship. The contractor agrees to post in conspicuous places, available to employees and licants for employment, notices to be provided by contracting officer setting forth the provisions of this Equal Opportunity clause.

(2) The contractor will, in all solicitations or advertisements for employees placed by or on behalf of the contractor, state that all qualified applicants will receive consideration for employment without regard to race, color, religion, sex or national origin.

(3) The contractor will send to each labor union or representative of workers with which he has a collective bargaining agreement or other contract or understanding, a notice, to be provided by the agency contracting officer, advising the labor union or workers' representative of the contractor's commitments under this Equal Opportunity clause, and shall post copies of the notice in conspicuous places available to employees and applicants for employment.

(4) The contractor will comply with all provisions of Executive Order No. 11246 of September 24, 1965, as amended, and of the rules, regulations, and relevant orders of the Secretary of Labor.

(5) The contractor will furnish all information and reports required by Executive Order No. 11246 of September 24, 1965, as amended, and by the rules, regulations, and orders of the Secretary of Labor, or pursuant thereto, and will permit access to his books, records, and accounts by the contracting agency and the Secretary of Labor for purposes of investigation to ascertain compliance with such rules, regulations, and orders.

(6) In the event of the contractor's noncompliance with the Equal Opportunity clause of this contract or with any of the said rules, regulations, or orders, this contract may be cancelled, terminated or suspended in whole or in part and the contractor may be declared ineligible for further Government contracts in accordance with procedures authorized in Executive Order No. 11246 of September 24, 1965, as amended, and such other sanctions may be imposed and remedies invoked as provided in Executive Order No. 11246 of September 24, 1965, as amended, or by rule, regulation, or order of the Secretary of Labor, or as otherwise provided by law.

(7) The contractor will include the provisions of paragraphs (1) through (7) in every subcontract or purchase order unless exempted by rules, regulations, or orders of the Secretary of Labor issued pursuant to Section 204 of Executive Order No. 11246 of September 24, 1965, as amended, so that such provisions will be binding upon each subcontractor or vendor. The contractor will take such action with respect to any subcontract or purchase order as the contracting agency may direct as a means of enforcing such provisions including sanctions for noncompliance: *Provided, however,* That in the event the contractor becomes involved in, or is threatened with, litigation with a subcontractor or vendor as a result of such direction by the contracting agency, the contractor may request the United States to enter into such litigation to protect the interests of the United States.

U.S. Dept. of the Interior
Bureau of Land Management

ENVIRONMENTAL ANALYSIS WORKSHEET

Remarks: Checklist pertains to immediate site where drilling site will be located.

STAGES OF IMPLEMENTATION	Geothermal Test Hole - drilling, testing, restoration			
DISCRETE OPERATIONS	Site Preparation	Drilling	Restoration	REMARKS
I. NONLIVING COMPONENTS				
A. AIR				
Dust from earth movement	-L		-L	
Diesel fumes	-L	-L	-L	
Traffic dust	-L	-L	-L	
B. LAND				
Soil erosion				Will not occur if stipulations
Regrade	-L		+L	are followed.
Sump construction				
operation		0		
Culvert installation	-L	0	0	
C. WATER				
Silting	-L	0	0	Will not occur if stipulations
Surface run-off	0	0	0	are followed
Oil pollution		0	0	
Sewage		0		
Drilling cuttings & mud		0	0	
Thermal degradation		0		
Ground water	0	?		Not expected to be significant.
II. LIVING COMPONENTS				
A. PLANTS (AQUATIC)	-L	0	0	
B. PLANTS (TERRESTRIAL)	-L	0	+L	Reseeding of disturbed area planned.

STAGES OF IMPLEMENTATION									
DISCRETE OPER.		Site Prepara-tion	Drilling	Restoration					REMARKS
C. **ANIMALS (AQUATIC)**		-L	0	0					Will not occur if stipulations are followed.
D. **ANIMALS (TERRESTRIAL)**									
Non-game mammals (dom. livestock)		-L	-L	-L					No significant impact can be anticipated.
Game mammals		-L	-L	-L					
Birds		-L	-L	-L					
III. **ECOLOGICAL INTERRELATIONSHIPS**									
A. **ECOLOGICAL PROCESSES**		0	0	0					
IV. **HUMAN VALUES**									
A. **LANDSCAPE CHARACTER**									
Inharmonious (sound)		-L	-L	-L					Traffic & drilling
Aesthetics		-L	-L	+L					Noise, dust, equipment
B. **SOCIOCULTURAL INTERESTS**									
Long-term social values		0	+M	0					Result of information gained through drilling.

-M = Moderate negative impact

-L = Slight negative impact

0 = No change

+L = Slight positive impact (improvement)

+M = Moderate positive impact (improvement)